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BRITISH COLUMBIA HYDRO AND POWER AUTHORITY

ALTERNATE ENERGY SOURCES
A LITERATURE REVIEW

SYSTEM ENGINEERING DIVISION

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ALTERNATE ENERGY SOURCES

A LITERATURE REVIEW

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SECTION 1.0 - SUMMARY

The alternate energy sources and their relative advantages and disadvantages for use in British Columbia are summarized in Table 1.1 (located as a pull-out table at the end of the report). Of the conventional energy sources available, hydro-electric power continues to offer the most economic renewable power and storage facility. However, the overall benefits of hydro projects are being questioned because of the large land area inundated by the reservoirs and the effects on fish and wildlife. Coal is the only fossil fuel available in sufficient quantities for major economic power generation in the province, and although land requirements are relatively small, the environmental impacts associated with the mining operation and the generation of power can be considerable. Candu reactors provide relatively economic power generation, however, public awareness in British Columbia of nuclear power technology is generally not at a level where a decision can be made by the public as to its acceptability. Breeder reactors could offer large resources of economic energy, but not within the next 20 years.

Non-conventional sources of power will generally be more expensive than hydro-electric and conventional thermal power. Fusion reactors may provide abundant power but probably not until after the year 2000. Solar space heating may have potential in an economic fuel saving role in 5 to 10 years. Solar domestic hot water heaters can provide economic energy today, but with only minor impact on the energy requirements in British Columbia. Thermal-electric power generation using solar energy is not a contender as an alternate energy source for the province's near future as it would cost 10 to 25 times more than today's economic power and will require similar land use to hydro projects. Photovoltaic cells will be even more expensive and land

intensive than thermal-electric generation until cell costs are reduced by a factor of 100 and efficiencies improved. Orbiting photovoltaic satellites will be economically out of reach until launching costs can be reduced by a factor of over 100.

Organic farms might provide power at reasonable costs, but would require large land areas especially for British Columbia growing conditions. Wind driven generators are generally uneconomic in British Columbia locations for large scale dependable power generation and would require large land plots and extensive transmission facilities. However, small wind driven generators might provide economic power in isolated, windy locations.

Ocean thermal gradients, while offering potential in some parts of the world, are completely uneconomic because of low temperature gradients along the Pacific northwest coast. Waves have the potential to provide large quantities of energy if the predicted efficiency of power generation can be achieved at slightly lower costs than presently anticipated. Tidal barrage schemes may produce power in some locations along the British Columbia coast at costs which could become economic in the near future. However, the environmental effects and engineering details of such schemes have not been evaluated in depth. Ocean currents have only a very low potential for power production therefore technological development is doubtful. Up to a thousand megawatts of geothermal power might be economically developed at Meager Creek, near Pemberton, and solid waste may provide a small amount of energy in Vancouver if the benefits of waste re-cycling are considered.

SECTION 2.0 - INTRODUCTION

Energy for the world can be classified as originating from one of six independent sources; solar, fossil fuels, nuclear, tidal, geothermal or solid waste*. Harnessing this energy to perform useful work is a difficult task, requiring a well planned strategy, large developments with lead times of over 10 years and capital expenditures reaching billions of dollars.

No one report can cover in detail a topic as broad as the energy spectrum. This report therefore presents only a review of the current literature on the subject, with the specific goal of providing an evaluation of the potential electrical energy sources and generating alternatives as they relate to British Columbia and B.C. Hydro.

To evaluate the many revived power generation alternatives and new concepts, as well as the developed sources, this report has been divided into conventional sources (hydro**, fossil fuels, nuclear fission) and non-conventional sources (nuclear fusion, solar, tidal, geothermal, and solid waste). Information on the conventional sources of power generation is readily available to the public, therefore the discussion of this subject is intentionally brief. For convenience, source references are provided at the end of Sections 3.0, 4.0 and 5.0. Generation technology is discussed along with the energy resources and, as many of the non-conventional energy sources could provide only

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* Solid waste is technically considered by some to be a fossil fuel.

** The hydro-electric resource is technically a member of the solar energy sources but is discussed separately in view of its relative importance in B.C.

intermittent power, Section 5.0 contains a review of the possibilities for energy storage. A glossary of technical terms is provided in Appendix A.

In examining the potential sources for electric power development, it is essential to keep in perspective the scale of the potential development in relation to the possible annual increases required to meet the increasing demand for electric power on the B.C. Hydro system. For example, whereas nuclear fission, and in the future nuclear fusion, have enormous potential in meeting future power requirements, in British Columbia (B.C.) solar power and wind power are not expected to make more than minor contributions in complementing the other major sources of power in specific applications.

B.C. Hydro's existing electric power grid is supplied mainly from renewable hydro-electric energy sources (approximately 5500 MW of installed nameplate capacity), with thermal plants, gas turbines and diesel plants supplying the balance (approximately 1250 MW installed nameplate capacity). These latter are used to meet peak load requirements in the Lower Mainland and Vancouver Island and supply base load to small, isolated areas.

The non-conventional sources discussed in this report are not under consideration for widespread use within the next 15 years. Rather, it is hoped that energy sources showing potential for development can be identified for long term studies of their technical viability as well as their social and environmental effects.

SECTION 3.0 - CONVENTIONAL RESOURCES

The energy sources conventionally used throughout the world for large scale power generation are hydro-electric, fossil fuels, and nuclear fission.

This brief discussion of conventional resources is included to provide a basis for comparison with the non-conventional resources and to discuss new generating technologies for fossil fuels and nuclear fission. References are provided for those wishing to review these subjects in greater depth.

3.1 HYDRO-ELECTRIC GENERATION

Solar heating of the oceans and the natural convection cycle continuously regenerate the resource base for hydro-electric power. The total energy of flowing fresh water in the world is .275 Q/yr*, with .0426 Q/yr (Ref. 1, pages 155-156) considered developable under average flow conditions. Nations with major hydro-electric potential resources are (Ref. 1, page 173):

	Percent
China	13.5
U.S.S.R.	11.1
U.S.A.	7.2
Zaire	6.7
Canada	5.5
Brazil	5.3

---

* Q - a unit of energy equalling 10^{18} Btu.

3.1 HYDRO-ELECTRIC GENERATION - (Cont'd)

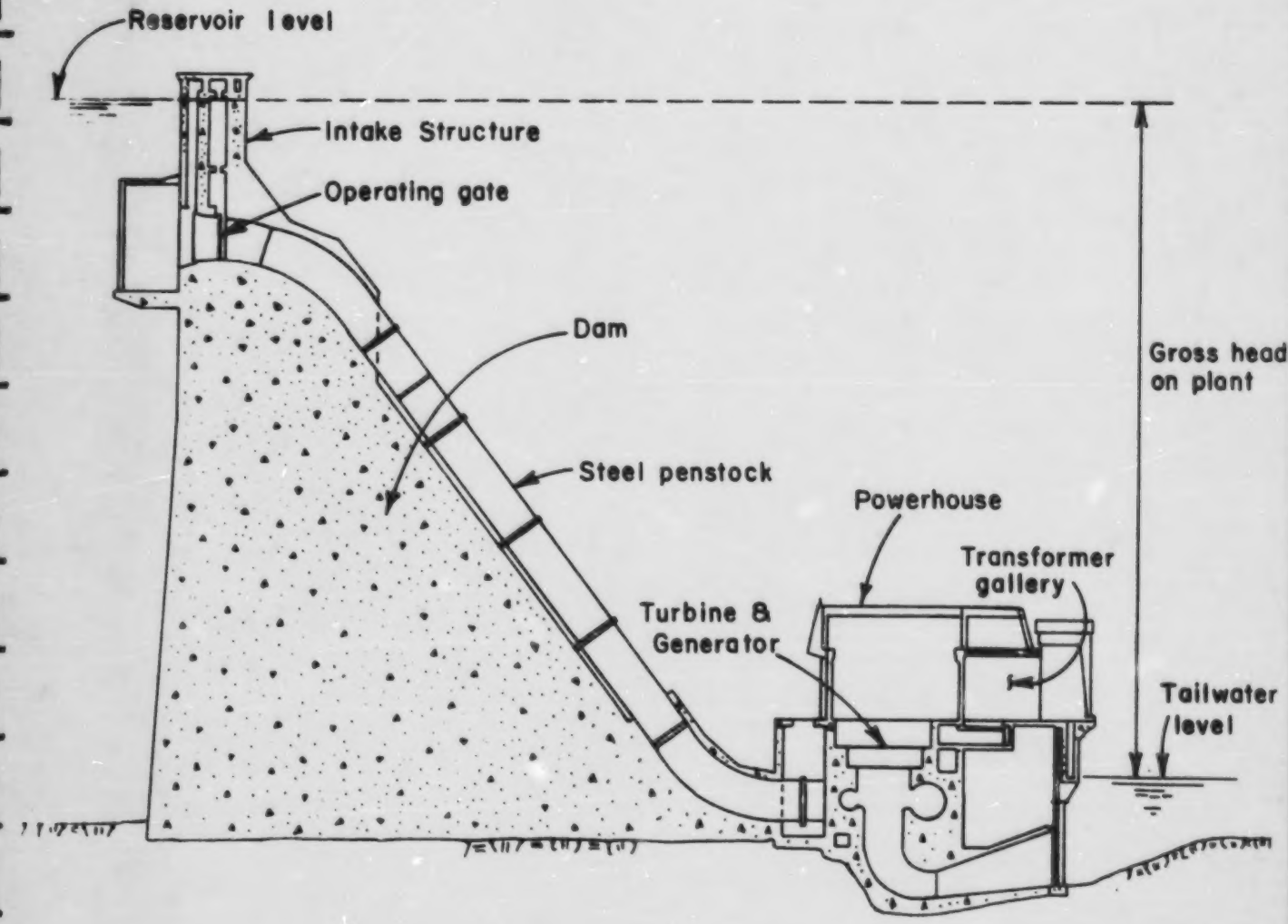
The hydro-electric potential in Canada is approximately 2.34×10^{-3} Q/yr, of which 30 percent have been developed. (Ref. 1, pages 176-7.) In 1972, B.C.'s technically developable power was listed as 28,000 average MW (Ref. 2) or 8.4×10^{-4} Q/yr with 5500 MW nameplate capacity presently installed (January 1978). The total B.C. Hydro integrated system generating capability including gas turbine, conventional thermal, diesel and others is only 6750 MW. Costs of proposed hydro-electric developments in British Columbia for the upcoming 10 years generally range from $500 - $850/kW or 15-25 mills/kWh.

Development of hydraulic resources is conventionally achieved by damming a river to develop a head for power generation (Fig. 3.1). The simplicity of the equipment provides high reliability and typically 80-90 percent overall efficiency. Energy storage on an annual basis is provided by the reservoir, the area of which could range from less than 1 acre/GWh on a project such as Seven Mile to about 30 acres/GWh at the G.M. Shrum Peace River Project. A large reservoir such as Williston Lake on the Peace River also provides energy storage for downstream facilities.

British Columbia is heavily dependent on hydro-electric power and future generation schemes could well continue this trend.

Comparing the benefits to the disadvantages of hydro projects is of increasing importance and is properly dealt with by a number of authors (Refs. 3 and 4). Benefits include:

- use of renewable energy resource
- flood control
- public water supply
- recreation
- irrigation



HYDRO ELECTRIC SCHEME

Figure 3.1

3.1 HYDRO-ELECTRIC GENERATION - (Cont'd)

- conservation of alternate depleatable resources
- no waste products, air pollution or heat rejection
- quick start up and loading capacity
- yearly energy storage
- low operating cost

Disadvantages: (some of which can be mitigated)

- relocation of people, wildlife and structures inundated by reservoirs
- change in river energy
- change from a river regime to a lake regime
- loss of agricultural and forest land
- blockage of migratory fish runs
- socio-economic impacts on adjacent communities
- remote from load centres

3.2 FOSSIL FUELS

Fossil fuels are comprised of coal, oil, natural gas, oil shale and tar sands. They will probably continue to be the predominant world energy source for at least 20 years, and after that will continue as the major raw material source for the chemical industry. An estimate of the world's measured reserves of fossil fuels is 30 Q (Ref. 1, page 255). The undiscovered and marginal resources have been estimated at 450 Q, with perhaps 216 Q (Ref. 6) eventually recoverable.

Electrical power generation from fossil fuels is conventionally accomplished through the use of steam turbines, gas turbines and diesel engines. Non-conventional fuel cells and MHD units will also be discussed in this section to provide information on the more efficient

3.2 FOSSIL FUELS - (Cont'd)

fossil fuel generation possibilities. As well, gasification, liquefaction and fluidized bed combustion of coal are discussed because they offer promising alternatives to conventional coal-fired thermal plants.

(a) Coal

Coal is by far the most abundant fossil fuel resource with estimated measured world reserves of 14 Q (Ref. 6, page 255). Undiscovered and marginal resources may be 320 Q, with 192 Q (Ref. 6) eventually recoverable. The world distribution of coal resources (Ref. 1, page 28) is as follows:

	Percent
U.S.S.R.	56
U.S.A.	19
Peoples Republic of China	7
Canada	1
Other	17

Ninety-nine percent (99%) of the Canadian coal resources are located in Saskatchewan, Alberta and B.C. (Ref. 1, page 56.)

British Columbia's total coal reserves and resources could range from 2 to 6 Q, 53 percent of which is in the Interior belt, 43 percent in the Rocky Mountain belt and 4 percent in the Coast belt. Most of this is classified as high quality coking coal (Ref. 7, page 5 assuming 116 to 301 billion short tons is approximately 2 to 6 Q). Thermal coal reserves for the province have been estimated at .044 Q. (Ref. 8, calculated from Exhibit 4-11.)

North American coal has been primarily developed through underground mining in the past. More recently strip mining and

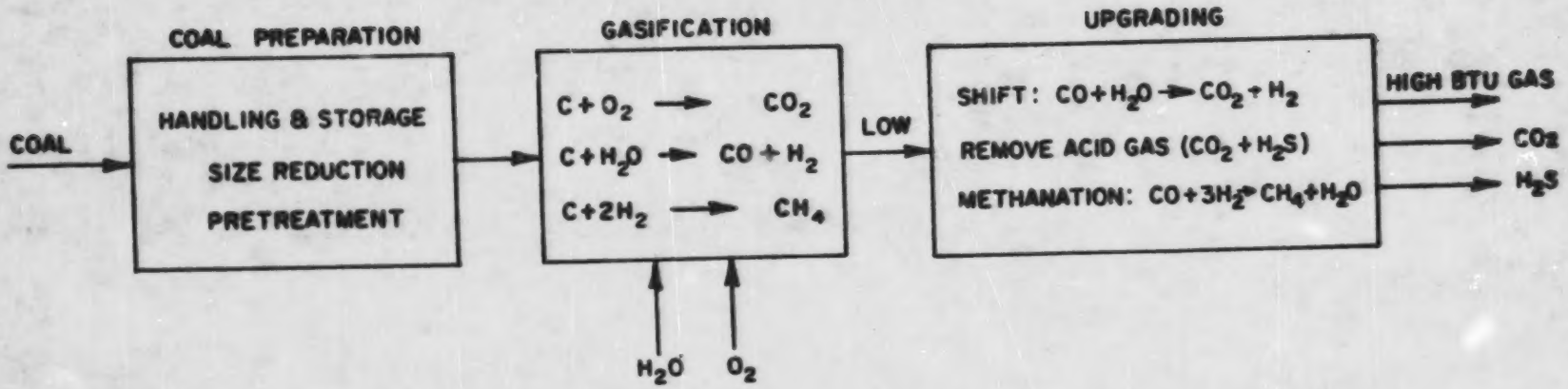
open pit techniques have been used to recover surface deposits and presently produce over 50 percent of the coal output.

Electrical power generation from coal is conventionally accomplished through the use of steam turbines. Research and development of non-conventional methods, such as gasification, liquefaction and fluidized bed combustion, attempt to reduce the contaminant emissions and enable more efficient electric power generation. These techniques will be discussed briefly in the following section.

(1) Gasification

Coal gasification involves the reaction of coal with a gasifying agent to yield a product that can be used either as a clean source of energy or as a raw material for chemical synthesis.

When an air-steam mixture is used to gasify the coal the product is a low-caloric gas (~150 Btu/scf, ~5500 kJ/Nm^3). Low-caloric gas is suitable for use as an energy source near its point of generation, but is not economically attractive for long distance transmission. If oxygen-steam mixture is used, an intermediate-caloric (~300 Btu/scf, ~11,000 kJ/Nm^3) gas is obtained. Intermediate-caloric gas can be used either as an energy source or as a synthesis gas for chemical synthesis. The high-caloric (~950 But/scf, ~35,500 kJ/Nm^3) synthetic pipeline gas (SPG) or substitute natural gas (SNG), which is similar to natural gas and contains over 90% v CH_4, is produced by further processing of intermediate-caloric gas. The coal gasification process is described generally in Fig. 3.2.



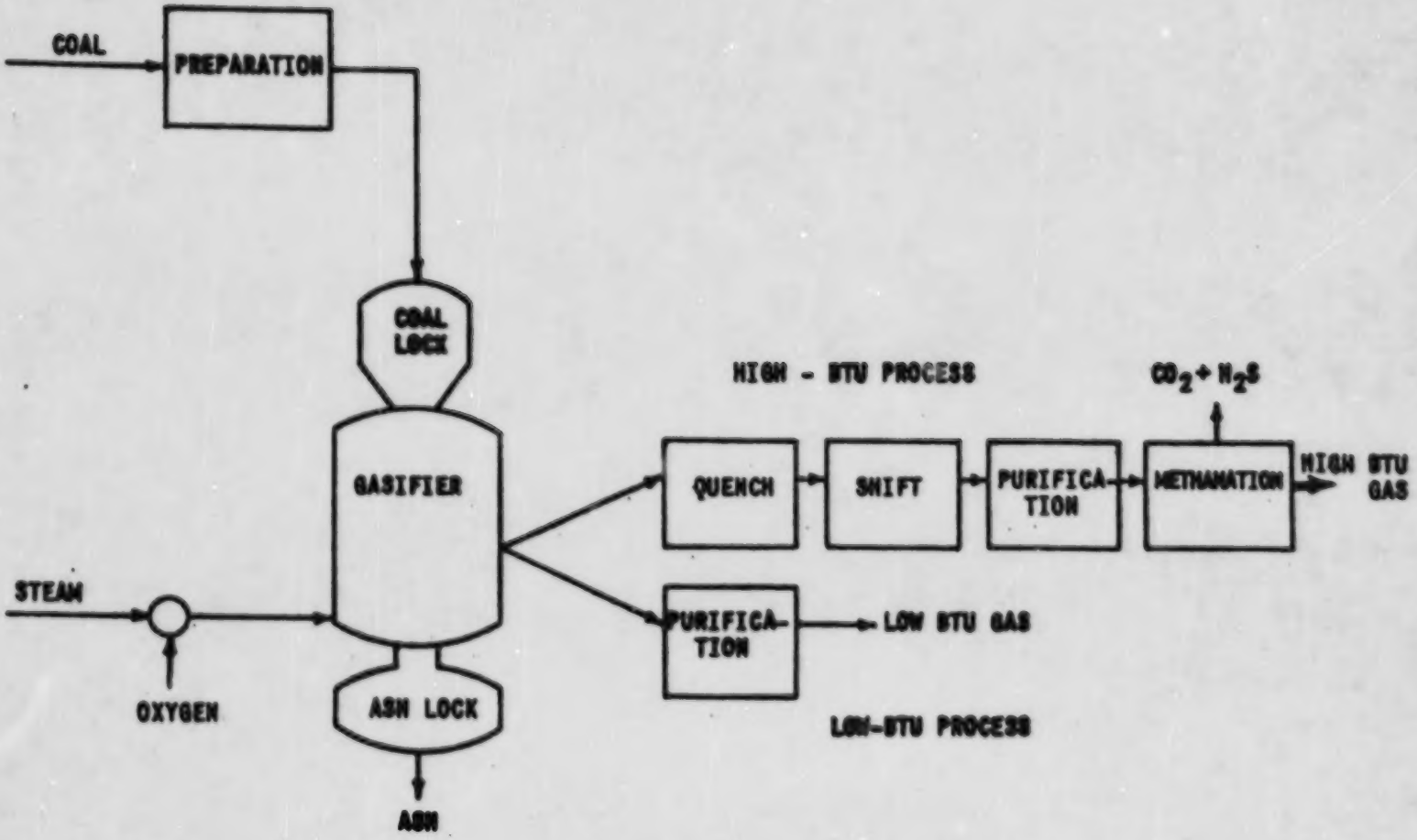
COAL GASIFICATION PROCESS

Figure 3.2

The technology to convert coal to gas has been known for many years, but various commercial processes have drawbacks which limit their general application. The ideal gasification process would be a fast, single-stage, continuous process able to gasify any type of solid fuel by using air as oxidizing medium, and producing clean high quality gas. Commercial processes, and processes under development, embody many of the characteristics of the ideal process, but as yet no single commercial process embodies all of these characteristics.

The best known commercial coal gasification processes which use oxygen (air) and steam as gasifying media are the gas producer process (normal pressure, fixed bed), Lurgi process (high pressure, fixed bed), Winkler process (normal pressure, fluidized bed) and Koppers-Tetzek process (normal pressure, entrained). Fixed bed and fluidized bed processes are suitable for gasification of non-caking and weakly caking coals with high ash fusion temperatures (>1200^{o}C). The entrained system is suitable for gasification of any coal (Fig. 3.3).

Estimates of the overall conversion efficiency to gas including process heat, range from 54 to 80 percent (Ref. 9, page 105) and costs range from 1 to 3 dollars per million Btu (Ref. 9, Table 1-52 and pages 1-120 and 1-121, escalated to $1976; and Ref. 8, page 50). The higher efficiencies and lower costs will be associated with the low Btu process. The first commercial SNG Lurgi plant, in North America, is scheduled for 1982.

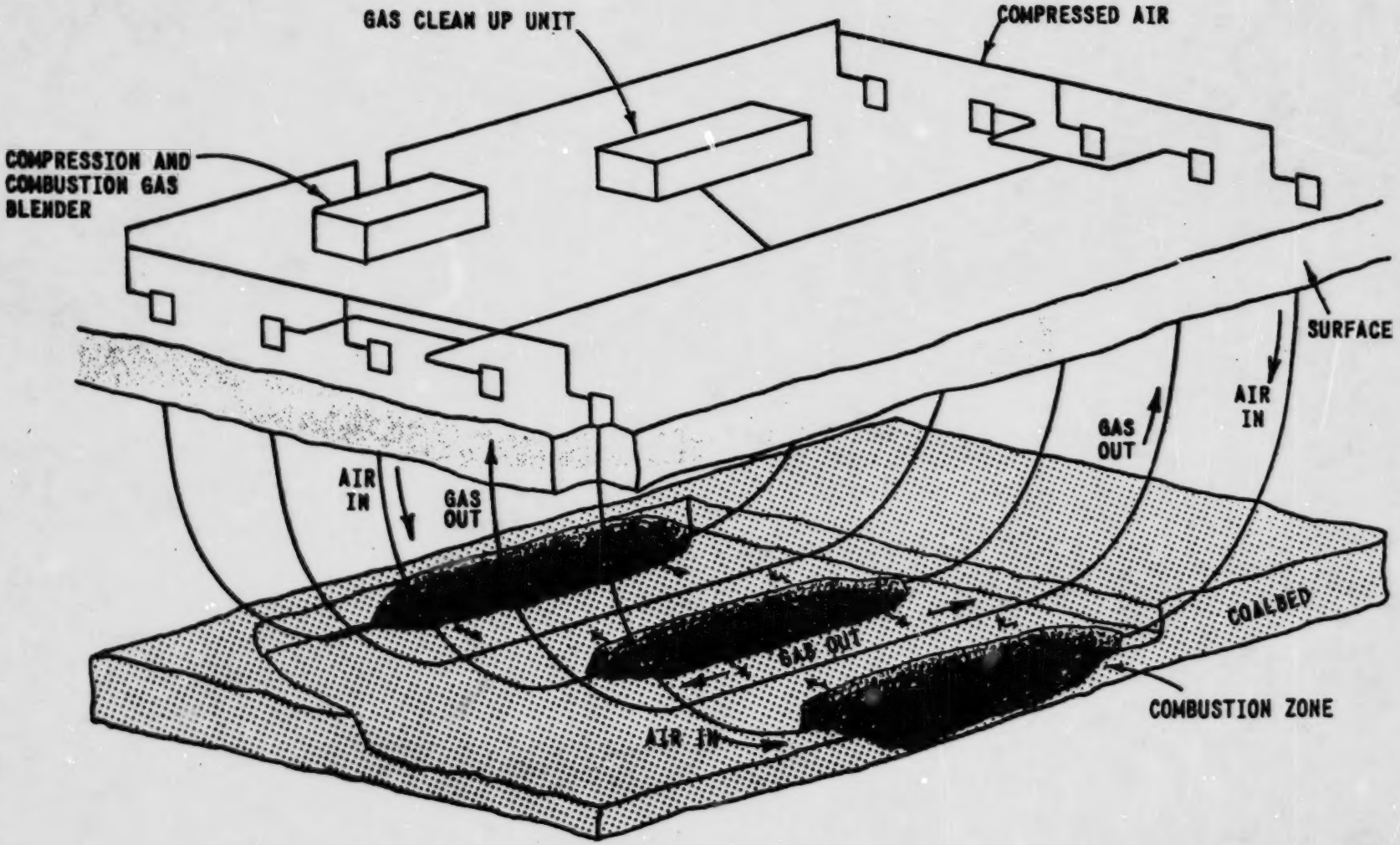


LURGI COAL GASIFICATION PROCESS
FIGURE 3.8

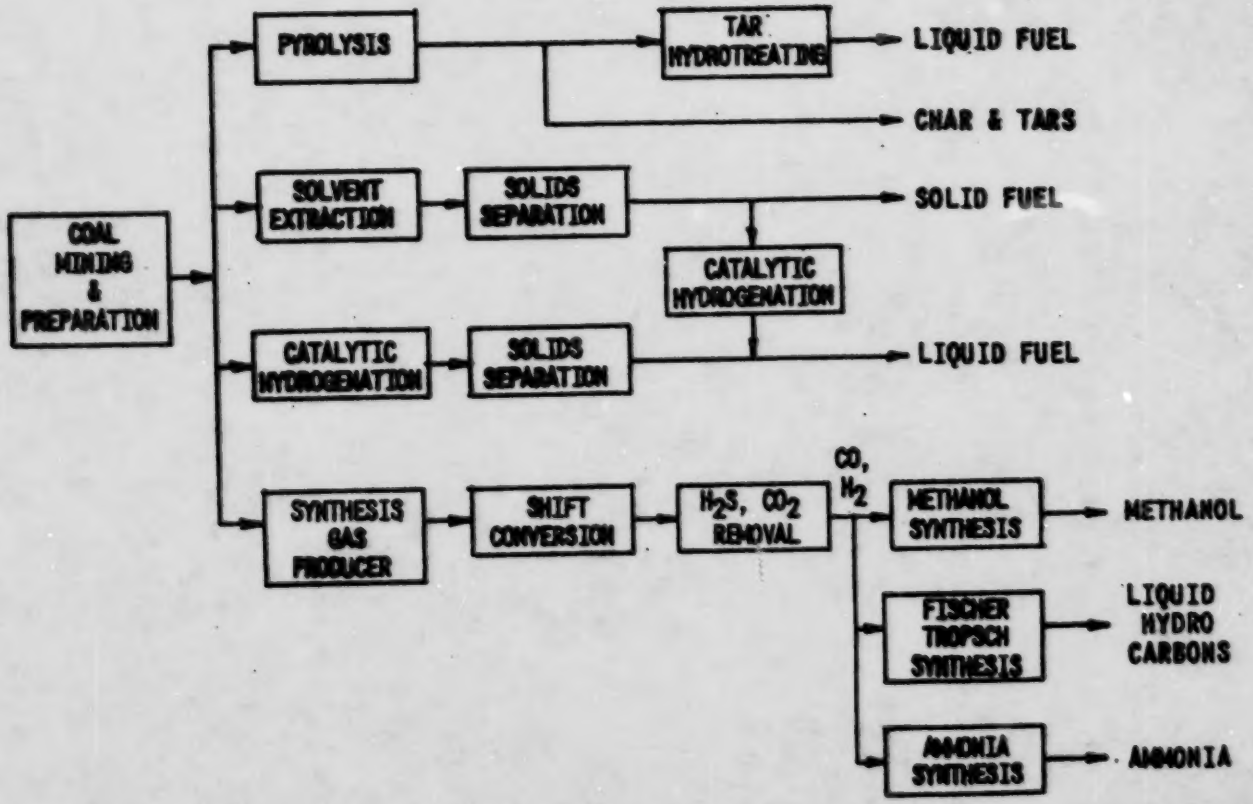
In-situ gasification of coal has as its objective the recovery of coal without mining. This method treats the coal seam and its containing strata as an in-situ gasification reactor. Air, oxygen-enriched air or oxygen with or without steam is injected into a coal seam and the generated gas withdrawn to the surface through an appropriate set of boreholes. The product gas might be utilized as a fuel or for chemical synthesis (Fig. 3.4). Commercial gas recovery using in-situ techniques began in the U.S.S.R. during the 1930s. Recently, test programs have been established at Hanna and Hemmer in Wyoming, and Forestburg in Alberta. Commercial development resulting from these programs will not take place within the next 15 years. This delay is primarily due to the problems in controlling the movement and collection of the gas.

(ii) Liquefaction

There were two routes to liquefy coal: synthesis and hydrogenation. In a synthesis process the first step is a total gasification of coal, and in hydrogenation process the direct hydrogenation is carried out under pressure in the presence of a suitable solvent. Both of these routes have been commercially proven. The possible liquefaction procedures are shown in Fig. 3.5. Overall energy efficiencies range from 62 percent (Ref. 10, page 1.107) to 78 percent (Ref. 8, page 55) and costs are comparable to gasification. (Ref. 10, Table 1-52 and Ref. 8, page 57.)



IN-SITU COAL GASIFICATION
FIGURE 3.4



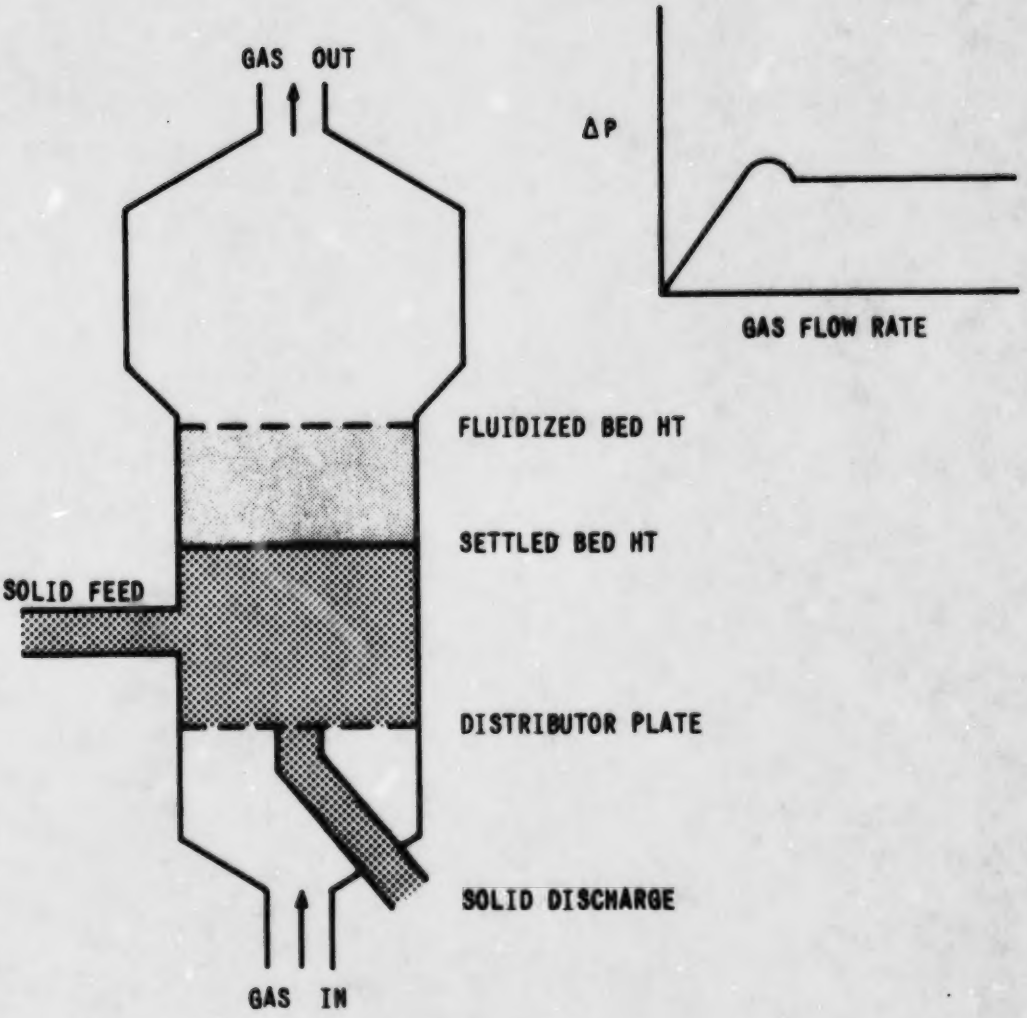
LIQUEFACTION ROUTES
FIGURE 3.5

Liquefaction of coal was used by Germany to produce gasoline during World War II. The U.S.A. is presently updating this process, however it is expected to be 10 years (Ref. 10, page 57) before construction of liquefaction plants can begin using the new, more economic technology.

(iii) Fluidized Bed Combustion

Fluidized bed combustion (FBC) is a process in which a selected fuel (coal) burns in a bed of some inert material; in the case of coal, this is the ash from the coal itself. The fluidization is illustrated in Fig. 3.6. At the bottom of the bed is a distributor plate which is perforated with many small holes so that air can be blown in evenly at sufficient velocity to fluidize the bed material. At low gas velocities the bed remains in its original settled state; the pressure drop across the bed increases with flow rate. The pressure will continue to increase until the pressure drop across the bed is equal to the downward pressure exerted by the solids resting on the porous plate. At this point the bed expands, increasing the free area for gas flow, which allows more gas to pass through the bed at the same pressure drop. This is the point of incipient fluidization.

With a further increase in gas velocity the particles become free to move about and the bed is fluidized. In this stage the bed has many characteristics of a fluid; viz. it has an appearent viscosity, obeys Archimedes' principle, maintains a surface interface horizontal, and flows from the vessel.



FLUIDIZED BED REACTOR

FIGURE 3.6

As the gas velocity becomes sufficient to throw the bed material in a state of turbulent motion, but not sufficient to blow it all out of the vessel, bubbles form in the bed, rise and break at the surface. Some people call it "boiling bed". If the gas velocity is increased still further, the terminal velocity of the particles is reached and the particles are carried out of the vessel.

If the inert material of the bed is hot enough (say 600 to 900°C) coal can be fed in and burnt producing heat to maintain the temperature. Normally the coal would be injected near the bottom of the bed where it is immediately distributed through the bed. Even at only 800°C the coal burns very rapidly and at any moment in time the actual amount of carbon present in the bed is very low indeed - often 1 percent or less.

Fluidized combustion has a number of distinct advantages over the conventional pulverized fuel combustion processes:

1. Burns variable fuels of low heating value.

2. Requires less fuel preparation.

3. Enables better gas emission control of SO_x and NO_x.

4. Has high heat release rates.

5. Enables efficient heat transfer within the bed.

High heat release rates and efficient heat transfer will enable much smaller boilers to be used when compared to conventional pulverized fuel boilers, resulting in major savings. The potential reduction in boiler size is particularly significant under pressure.

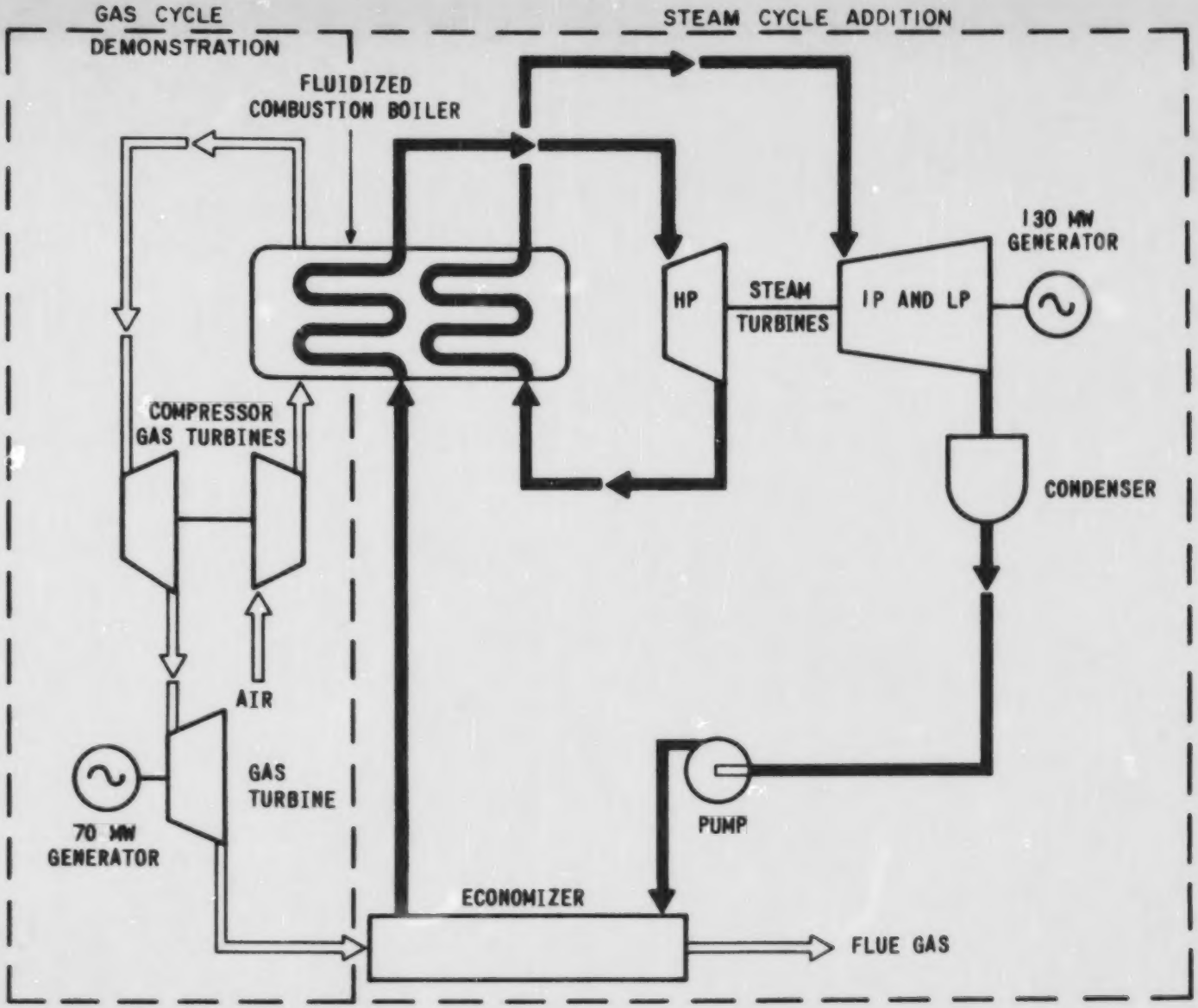
The full advantages of pressurized fluidized combustion will most probably be obtained in a combined cycle plant. With suitable integration of the gas and steam cycles, power generation efficiency can be improved by several percentage points. A combined cycle scheme is shown in Fig. 3.7.

The feasibility of any of the combined cycle schemes hinges on the technical capability of using combustion gases from coal to drive a gas turbine. Hitherto, attempts to develop coal-fired gas turbines have been generally unsuccessful due mainly to the erosion of turbine blades and/or the formation of bonded (corrosive) deposits on the blades. Fluidized combustion can overcome these problems because at the low combustion temperatures the ash passing through the turbine will be less abrasive, and volatilization of alkalis, which leads to the formation of bonded deposits, will be less.

Commercial availability for economic unit sizes will probably be in the mid 1990s.

(b) Crude Oil and Natural Gas

Crude oil and natural gas are the principal energy source in many parts of the world. They are commercially available, convenient and easy to use. The resource potential is as follows:



COMBINED CYCLE SCHEME

FIGURE 3.7

3.2 FOSSIL FUELS - (Cont'd)

TABLE 3.1

CRUDE OIL AND NATURAL GAS ENERGY CONTENT (Q)

	CRUDE OIL		NATURAL GAS	
	Proven or Probable	Ultimate	Proven or Probable	Ultimate
World Ref. 8, Table 5	1.73	11.1	1.95	10.1
Canada Ref. 14, P. 67	.053	.570	.074	.785
B.C. Ref. 14, P. 67	.001-.002	.014	.009	.040

Steam, gas turbines and diesel engines are presently used for conversion of crude oil and natural gas to electricity, however, the magnitude of the B.C. resource indicates that these sources are inadequate for long term thermal electric generation. They are, and will continue to be used for peaking power and remote generation, with a net installed capacity of 1251 MW presently in the B.C. Hydro system.

(c) Oil Shale

The oil shale resource may prove to be larger than crude oil and natural gas. Recovery of kerogen, a solid hydrocarbon wax, from the oil shale is already a commercial operation in the U.S.S.R. and the Peoples Republic of China. The rich resources of the western U.S.A. have not yet been found economic. Resource estimates are in Table 3.2:

TABLE 3.2

OIL SHALE ENERGY CONTENT (Q)

	Eventually Recoverable	Total Resource
World	1.1 (Ref. 8)	78 (Ref. 8) - 11,200 (Ref. 13, Volume II, page 15)
Canada	1.0 (Ref. 1, page 136)	Unknown
B.C.*	0	0

* Oil shale resources are known to exist on the Queen Charlotte islands and are suspected on Vancouver Island. No resource estimates are presently available.

After mining the shale, conventional extraction of kerogen requires heating (450°C) the crushed shale to allow the liquefied hydrocarbons to flow. The heavy oil and gas is then upgraded to synthetic crude. The potential environmental problems include air contamination by fumes and dust, water contamination by organics and trace elements, and land contamination by solid rejects. The efficiency of the extraction is about 75 percent (Ref. 1, page 146).

In situ recovery methods are also being contemplated. Underground cavities would be excavated and exploded to provide crushed shale. Steam, hot water or light petroleum passed through the crushed shale would release 35-50 percent (Ref. 1, page 147) of the oil for recovery from the cavity bottom.

Power generation from oil shales will be achieved with steam turbines, gas turbines, combined cycles and MHD units.

3.2 FOSSIL FUELS - (Cont'd)

(d) Tar Sands

The hydrocarbons contained in tar sands are too viscous to be extracted with conventional drilling methods, therefore, surface mining is followed by bitumen extraction and synthetic crude processing. In situ recovery techniques are also being developed to extend recoverable resources as per Table 3.3. (A comprehensive review can be found in Refs. 1 and 13.)

TABLE 3.3

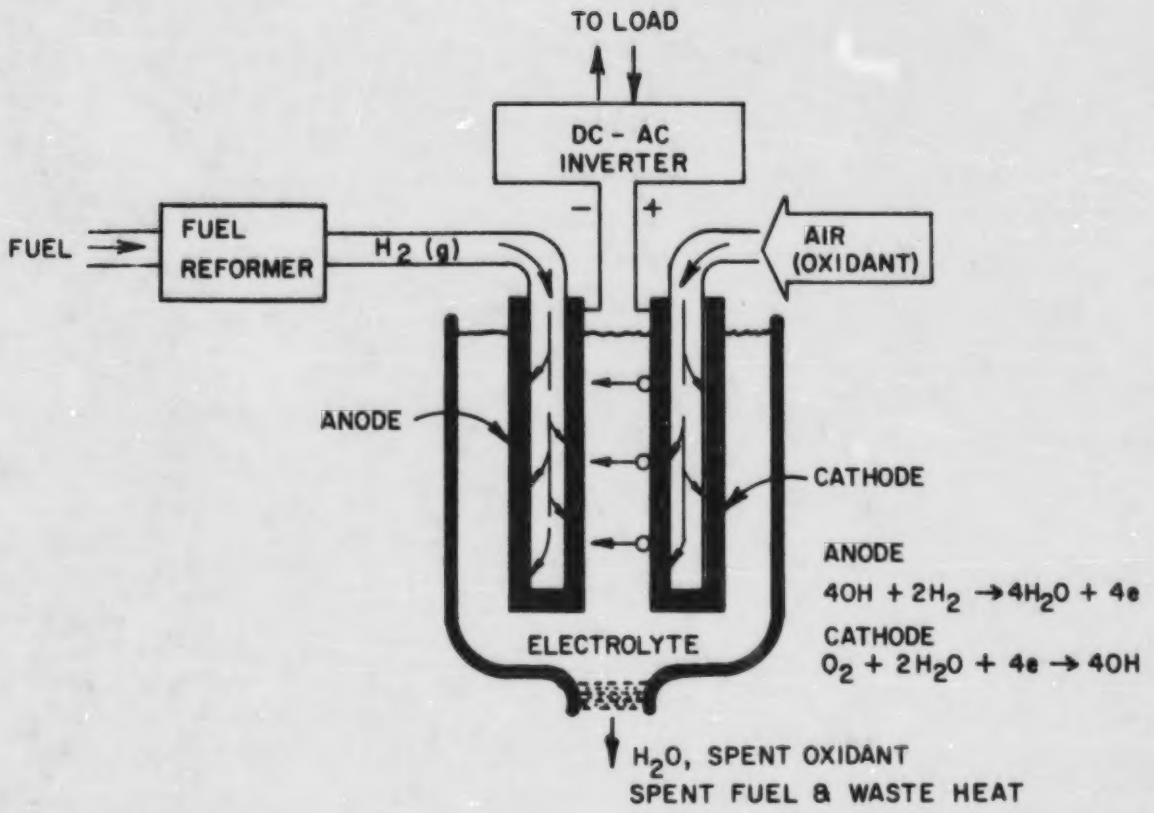
TAR SANDS ENERGY CONTENT (Q)

	Eventually Recoverable	Total Resource
World	1.7	6.5 (Ref. 8)
Canada	1.7 (Ref. 13, Volume I, page 160)	3.5 (Ref. 13, Volume II, page 1)
British Columbia	0	0

As with oil shales, power generation from tar sand petroleum may be achieved with steam turbines, gas turbines, combined cycles and MHD units.

(e) Fuel Cells

Fuel cells provide a direct conversion from chemical to electrical energy (Fig. 3.8). The fuel supply can be obtained from almost any hydrocarbon or hydrogen. A fuel reformer, is necessary to extract the hydrogen if hydrocarbon fuel is used. Either pure oxygen or air can be used as the oxidant. When the external direct current circuit is completed, an oxidation reaction takes place at the anode and a reduction reaction at the cathode. The water, spent oxidant, fuel and waste heat formed



FUEL CELL

Figure 3.8

by these reactions are continuously removed. Overall efficiencies including conversion to ac power are expected to range from 40 percent (Ref. 13, Volume II, page 291) to 55 percent (Ref. 10, pages 12-33) if hydrocarbons and air are used. These efficiencies can be maintained from 20 to 100 percent of the rated load. The higher efficiencies will be found in fuel cells operating at elevated temperatures of about 1000°C. If hydrogen and oxygen are used as fuel the overall efficiency might reach 60 percent (Ref. 8).

The pollution from fuel cells will be less than from conventional thermal plants. Thermal pollution will be low, especially if the waste heat is used in the fuel reformer step. NO_x emissions will be minimal if operated at low temperatures and sulphur must be removed from the fuel prior to use. Chemical pollutants will be similar to a combustion plant. Waste water disposal problems will have to be overcome.

To date, the only fuel cells operating have been 12 1/2 kW units producing 75 kW total power for residential use in a 9-year test program. A 100 kW plant is being developed by Westinghouse for use with gasified coal fuel. The fuel cells will be installed inside the fluidized bed coal gasifier.

Capital costs for fuel cells are expected to be about $230/kW using methane, synthetic natural gas (SNG) or hydrogen fuel and $450/kW for coal fuel with a gasifier reformer (Ref. 14). To achieve these costs the precious metal coating presently required as a catalyst on the anodes must be greatly reduced and a modular approach taken for mass production. To date, cell life has only been on the order of 1000 hours. This must be substantially increased before 1990 forecasted commercial operations can be met.

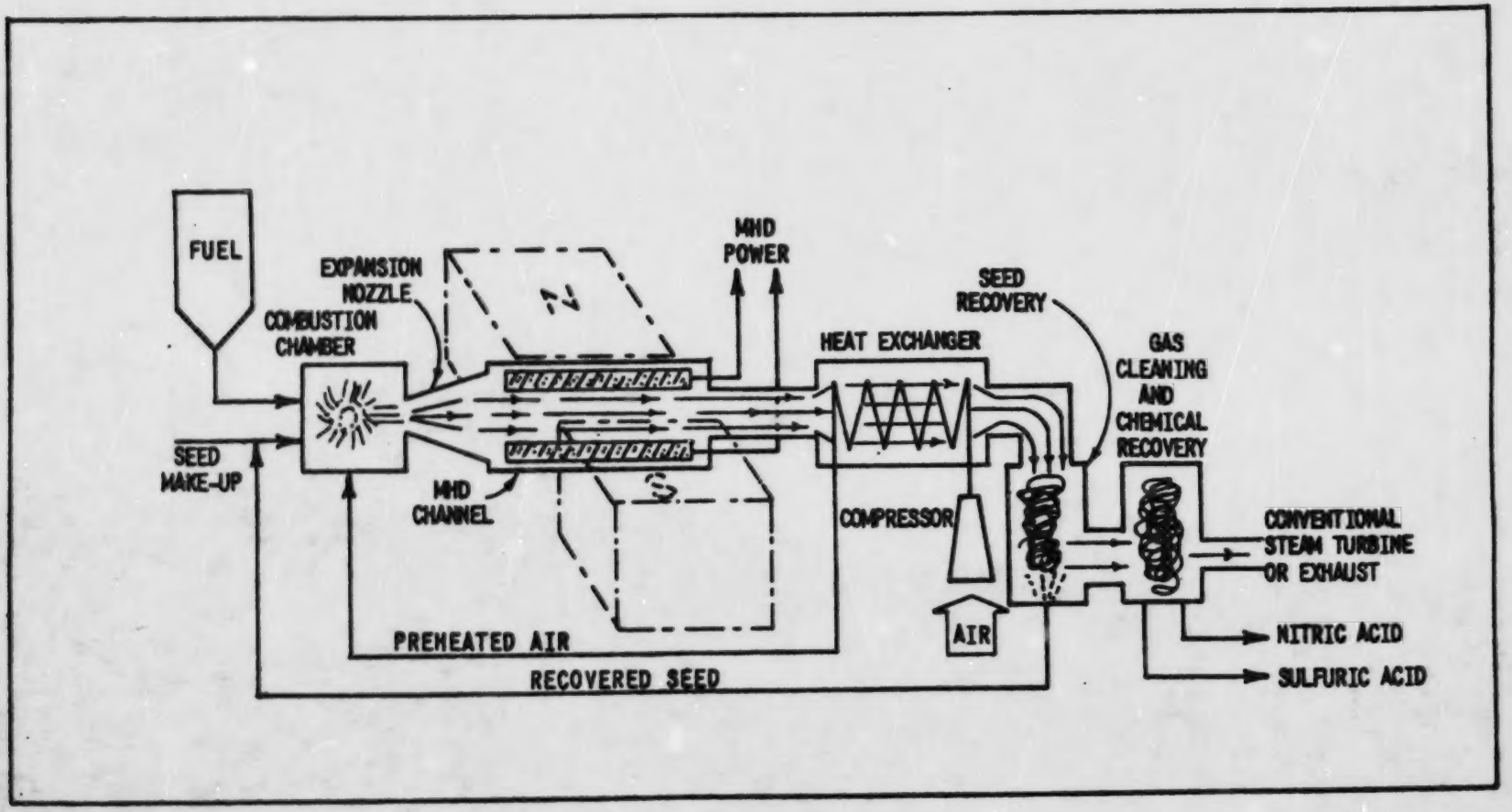
3.2 FOSSIL FUELS - (Cont'd)

(f) MHD

Magneto-hydro dynamics (MHD) is a process for the direct conversion of the kinetic energy contained in ionized flowing gas particles to electric energy (Fig. 3.9). Oil, gas or coal is combusted and the expanding gas accelerated through a nozzle and into a rectangular MHD channel. Ionization of the high temperature (2500°C) gas is increased with the addition of a seeding material such as cesium. In the channel, the charged gas particles flow perpendicular to an applied magnetic field, inducing an electric field perpendicular to both the magnetic field vector and the gas flow. In effect, the hot gas performs the function of an armature in a conventional generator. The dc output is converted to ac for use in an electric power grid.

If this method is used to top a conventional cycle the overall efficiency will probably reach 60 percent (Ref. 10). Closed cycle systems, with compressed pre-heated combustion air, will require temperatures of 1500°C and may give 50 percent (Ref. 10) overall efficiencies. A combination of liquid metal and inert gas is also being considered to replace the circulating air. When heated, the gas would expand and flow through the channel. The liquid metal would carry the electric charge. Overall efficiencies will approach 50 percent (Ref. 10).

The only open cycle pilot plant operating to date is the Russian U-25 system with 25 MW MHD generation and 50 MW steam generation. Smaller test bench operations are under way in the U.S.A. The liquid metal system has only produced a 1 kW output. MHD commercial development is not considered to be close at hand, and will probably be at least 20 years away. Some of the problems to overcome are the severe erosion of channel walls caused by high temperatures and high gas velocities, electrode performance and



MHD POWER GENERATION
FIGURE 3.9

life, and high NO_x and sulphur emissions. Capital costs are expected to be higher (Ref. 10) than those of conventional generating plants and have been assumed between 10 percent and 25 percent higher than steam cycle generation.

3.3 NUCLEAR FISSION

Nuclear fission offers the possibility of a large energy source from a small amount of fuel. A "thermal" or slow neutron is used to bombard a fissile nucleus, splitting it into smaller nuclei and "fast" neutrons. The mass of the resulting particles is somewhat less than the original particles as the disappearing mass is converted to energy according to the relation, energy = mass x speed of light squared ($E = MC^2$). Containment of the resulting fast neutrons is accomplished by surrounding the fuel with a moderating substance to impede the movement of the neutrons and release heat. Moderated neutrons continue the reaction as they collide with the fissile material. The energy released in the fission process is extracted in the form of heat by means of a reactor coolant.

The fuel input for nuclear fission can be uranium, plutonium or thorium. About 99.3 percent of naturally occurring uranium is fertile U-238, which can be made fissile with the molecular absorbtion of a thermal neutron to form fissle Pu-239. Fissle U-235 comprises about 0.7 percent of the naturally occurring uranium and only a trace is fissle U-234. All natural thorium is fertile Th-232 which can be converted to fissle U-233.

Conventional fission reactors are only able to use 1.5 percent of the possible heat energy content of natural uranium. The development of "breeder" reactors will allow 60 percent of the heat energy content to be released and will expand the fission resource base to include thorium.

3.3 NUCLEAR FISSION - (Cont'd)

The fission resource distribution is summarized in Table 3.4. Non-Communist World resources will provide just over 4 Q from conventional reactors, or over 164 Q from breeder reactors. Canadian resources will provide .7 Q from conventional reactors, or over 28 Q from breeder reactors, based on 1.7×10^6 tons of U_3O_8 yielding 1.5 Q from non-breeder reactors, (Ref. 13, Volume I, page 135) and breeder resources 40 times the non-breeder resource (assuming breeder reactors 60 percent uranium efficient and non-breeders 1.5 percent efficient).

Canadian uranium and thorium resources are found in Ontario in quartz pebble conglomerates. The uranium resources of northern Saskatchewan are associated with pitchblende and related deposits and there also exists the potential for uranium mining in B.C.

TABLE 3.4

FISSION RESOURCES
(Ref. 1)

	Uranium Resources (tonnes)	Thorium Resources** (tonnes)
U.S.A.	2,041,156	319,000
Canada	716,984*	160,000
Non-Communist World	4,023,948	1,728,000
Communist Nations	100,000 to 370,000	

* Canadian reserves and resources to \$33/kg of UO_2 as confirmed by Ref. 23.

** Thorium reserves and resources to \$26/kg.

The safety of nuclear generating facilities has been studied in depth by many sources (Refs. 10, 13, 22 and 23), and the major

3.3 NUCLEAR FISSION - (Cont'd)

concerns are reactor safety, radiation exposure and biological effects, radioactive waste management and disposal, and safe guarding of plutonium.

Public exposure to radiation from nuclear power is substantially lower than natural background radiation, however, a threshold level below which exposure produces no measurable damage has not been proven.

Some of the radionuclides, such as plutonium, formed in the fission process have radioactive half lives of about 25,000 years. This necessitates either permanent storage (disposal) or conversion of the waste radionuclides to relatively short-lived (30-year half lives) isotopes by extracting the actinides for re-use in reactors. To date, the spent fuel containing the waste radionuclides has been temporarily stored pending the development of long term storage and disposal facilities.

Prevention of accidental release of radioactivity from the reactor has been well engineered. Because of the low concentration of fissile material used in current reactor designs, a "nuclear explosion" is not possible.

(a) Candu Reactors

The term Candu refers to Canadian, heavy water moderated, natural uranium type power reactor. Low cost unenriched uranium, produced in Canada, is commonly burned as the fuel. Thorium dioxide can be substituted to produce a breeder type reactor. The heavy water used to moderate the fast neutrons causes the capital costs of Candu reactors to be somewhat higher than non-breeder reactors developed in the U.S.A. Pressurized heavy water, boiling light water or organic fluid can be used to cool the reactor and

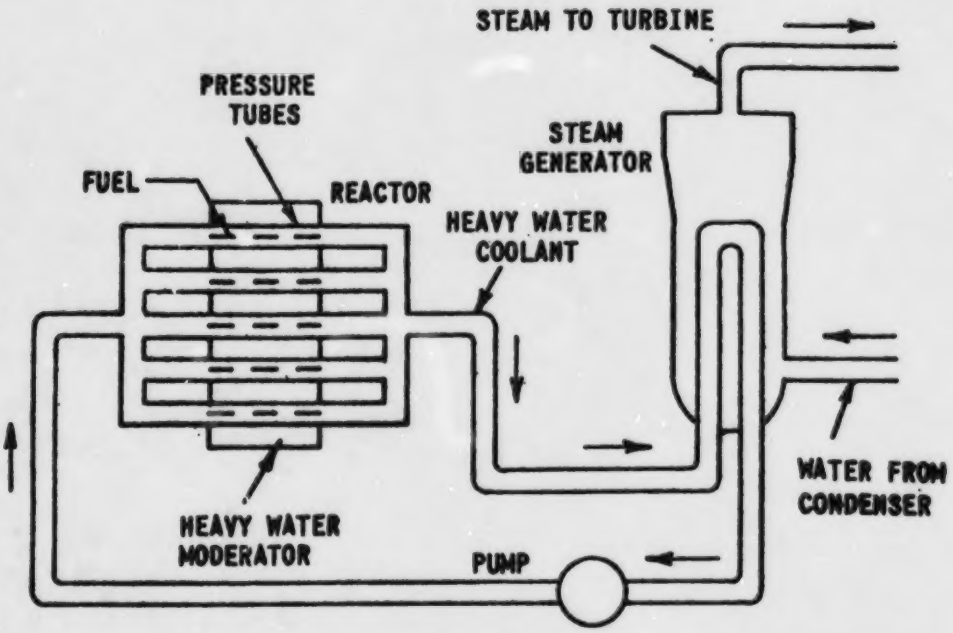
transfer the heat to a steam generator (Figs. 3.10 to 3.12). On-power refuelling is an advantageous operating characteristic and operating temperatures allow 32 percent overall efficiencies. Capital costs are expected to be $900/kW (Ref. 25) for steam generation installations, and fuel costs 2 mills/kWh.

(b) Light Water Reactors

Light water reactors (LWRs) are the most widely used method of harnessing nuclear fission energy. Inexpensive ordinary water is used as a moderator, effecting a 10 to 20 percent saving in capital costs over Candu type reactors. (Ref. 26.) The fuel must contain enriched UO_2 requiring costly processing before being burned. Cooling the reactor is accomplished by circulating either ordinary pressurized water (2000 psi) or ordinary boiling water (Fig. 3.13). Overall efficiencies of 32 percent are realized when coupled with a steam turbine. Energy costs are comparable to Candu reactors because the higher fuel costs balance the lower moderator capital costs. Capital costs of $770/kW (Ref. 26, $700/kW in $1975) and fuel costs $24/$10^6$ Btu (Ref. 27) or 3 mills/kWh at 32 percent efficiency are expected for plants being constructed.

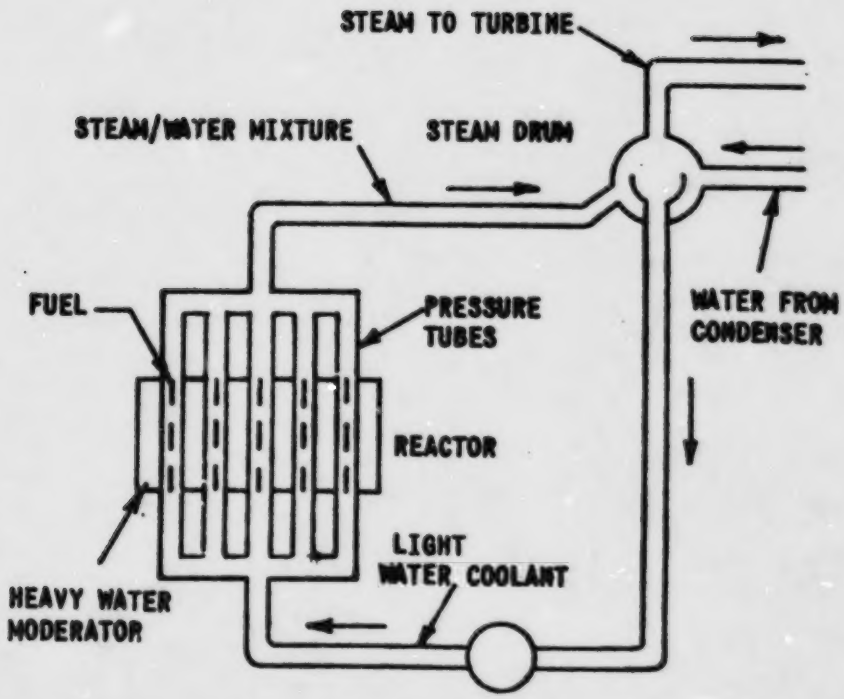
(c) High Temperature Gas Cooled Reactors

Helium coolant and a graphite moderator are used in the high temperature-gas cooled reactors (HTGCR), allowing elevated temperatures of from 850°C to 1000°C for electricity generation (or process heat for coal gasification). The fuel is a combination of highly enriched U-235 and fertile thorium, posing a possible weapons problem. Also, because thorium is used, the energy resource available to this reactor is somewhat larger than that for LWRs. (Ref. 13, Volume I, page 136.)

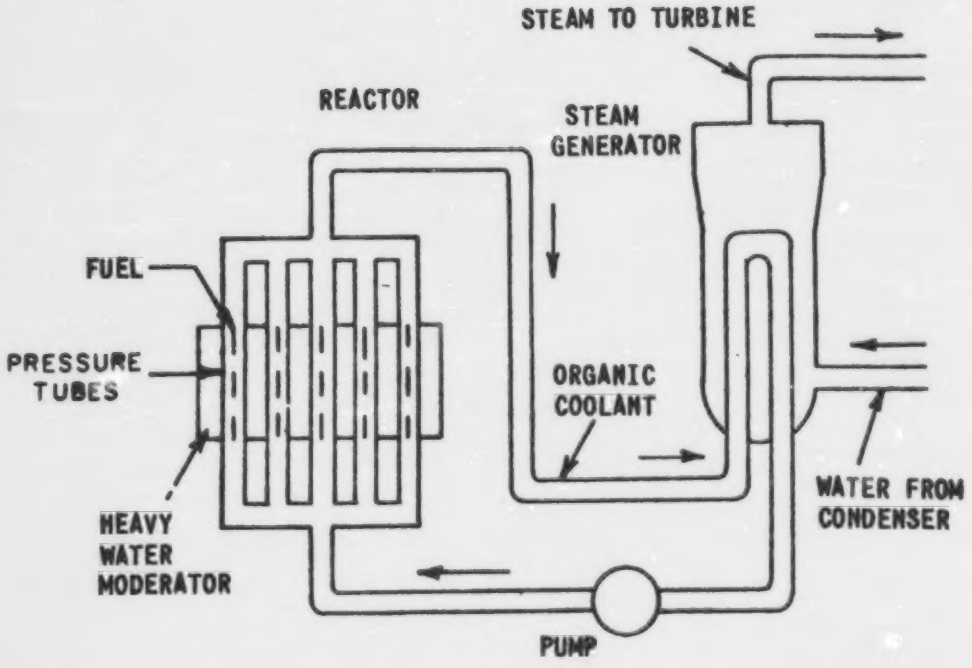


PHW CANDU REACTOR

FIGURE 3.10

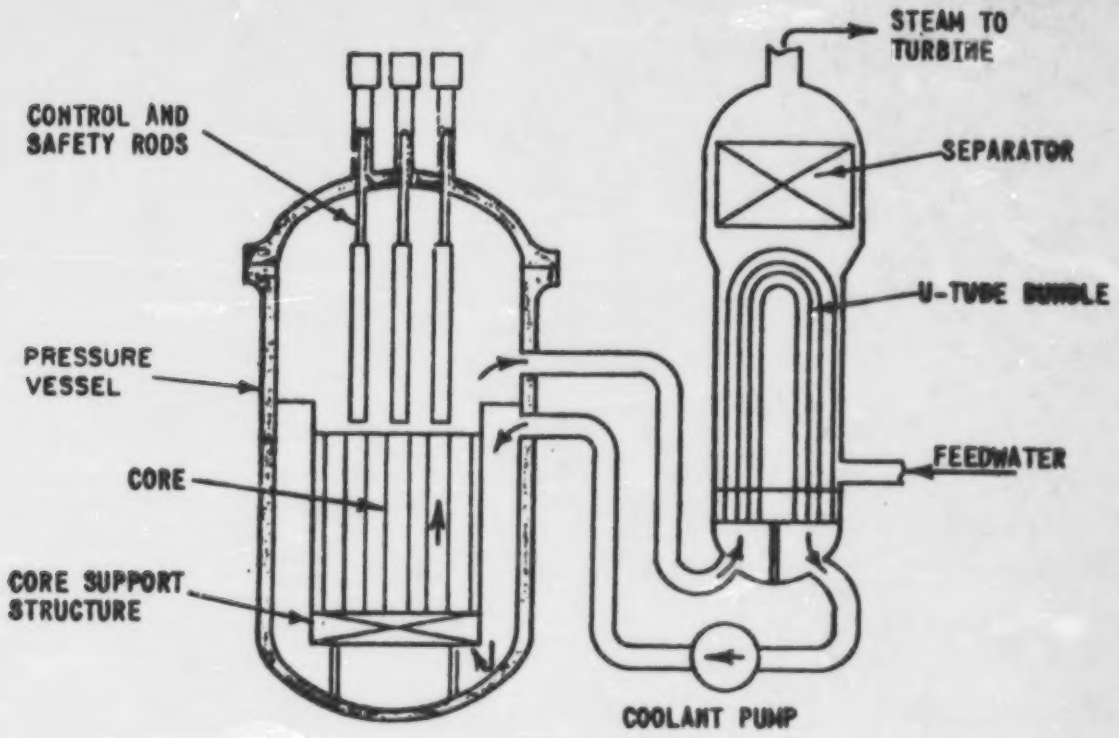


BLW CANDU REACTOR
FIGURE 3.11

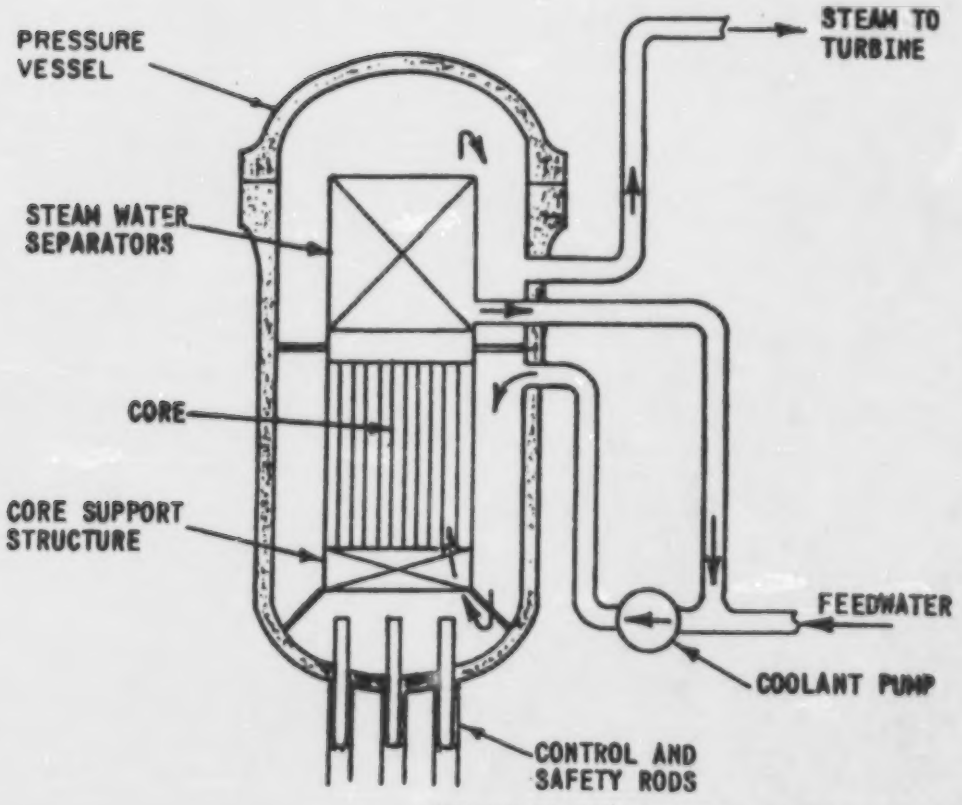


OCR CANDU REACTOR

FIGURE 3.12



PRESSURIZED LIGHT WATER REACTOR



BOILING LIGHT WATER REACTOR

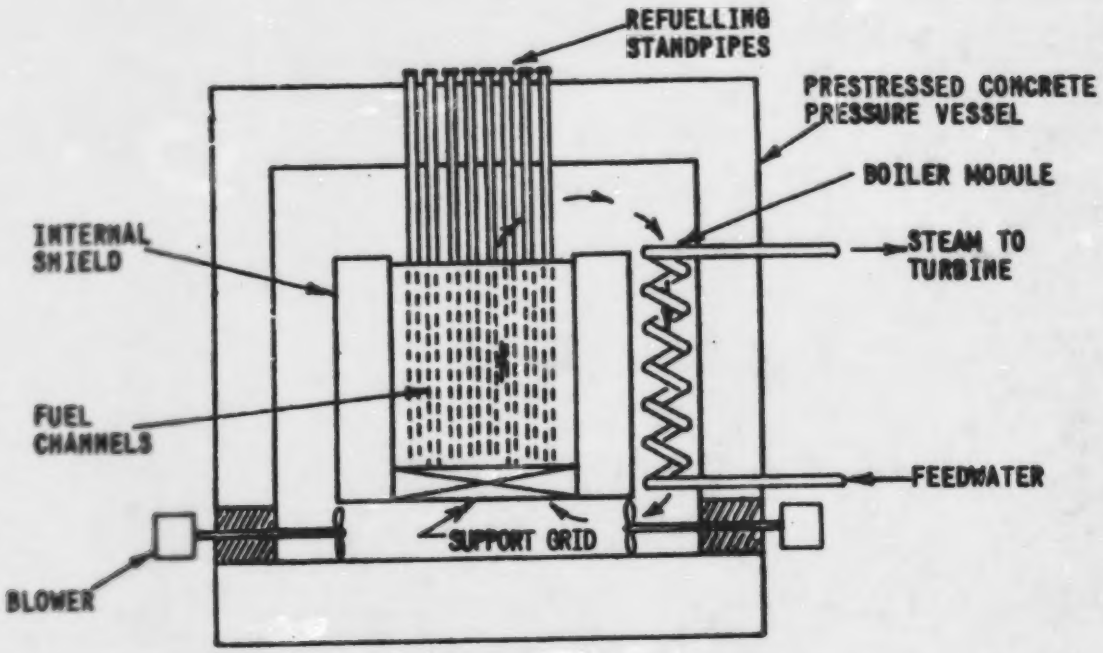
FIGURE 3.13

Power can be developed at 39 percent efficiency with a heat interchanger and steam turbine (Fig. 3.14) or at 45 percent efficiency by building a combined cycle unit directly into the reactor (Fig. 3.15) (Ref. 13, Volume III, page 60). A 40 MW unit began operation at Peach Bottom, Penn., in 1967, and a 330 MW unit is being commissioned at Ft. St. Vrain, Colorado. Capital costs of commercial HTGCRs are expected to be about $510/kW, (Ref. 10, page 6-56, $419/kW in $1974) or slightly lower than the LWRs, and fuel costs 2 mills/kWh (Ref. 10, page 6-48). Only the steam cycle HTGCR is available today in the U.S.A., however, a gas-turbine HTGCR demonstration plant is scheduled for 1983 (Ref. 13, Volume III, page 61) making a combined-cycle commercial plant possible for the early 1990s. Costs for the gas turbine reactor have been assumed similar to the steam cycle HTGCR in the summary (Table 1.1).

(d) Breeder Reactors

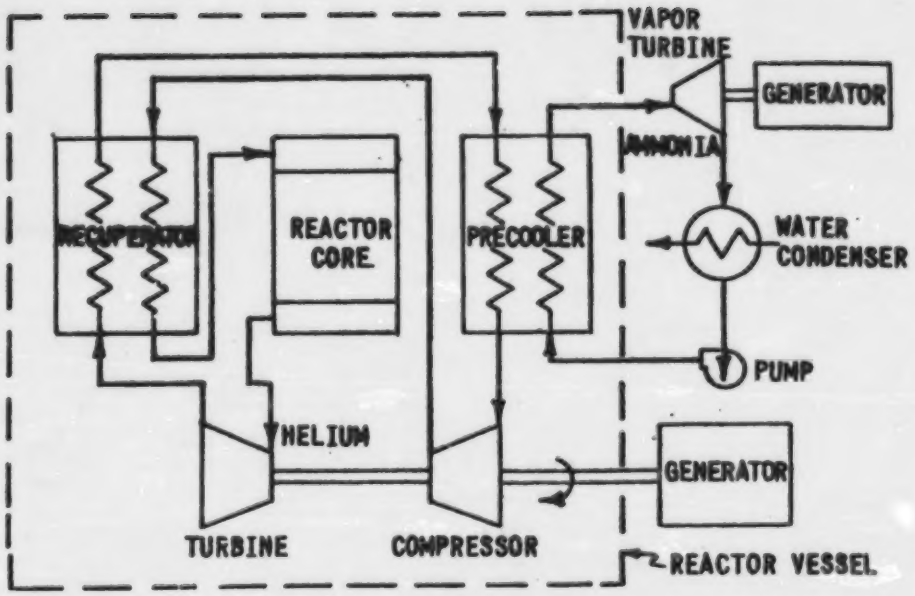
Liquid metal fast breeder reactors (LMFBR) use a combination of fissile and fertile fuel to expand the resource base. High temperature gas or liquid sodium is expected to be used to cool commercial breeder reactors (Fig. 3.16).

The reactor core is fissile Pu-239 and the surrounding blanket is fertile U-238 or Th-232. The high density coolant keeps the neutron velocity in the reactor high so that a high breeding ratio occurs. No moderator is necessary. Low pressure sodium provides safe operating pressures but reacts vigorously with water and burns in air at high temperatures. An intermediate heat exchanger loop isolates the reactor and irradiated sodium from the steam generation cycle. Overall efficiencies will reach 42 percent (Ref. 29) once commercially perfected and capital costs are expected to be $590/kW (Ref. 10, page 6-70, $487/kW in $1974).

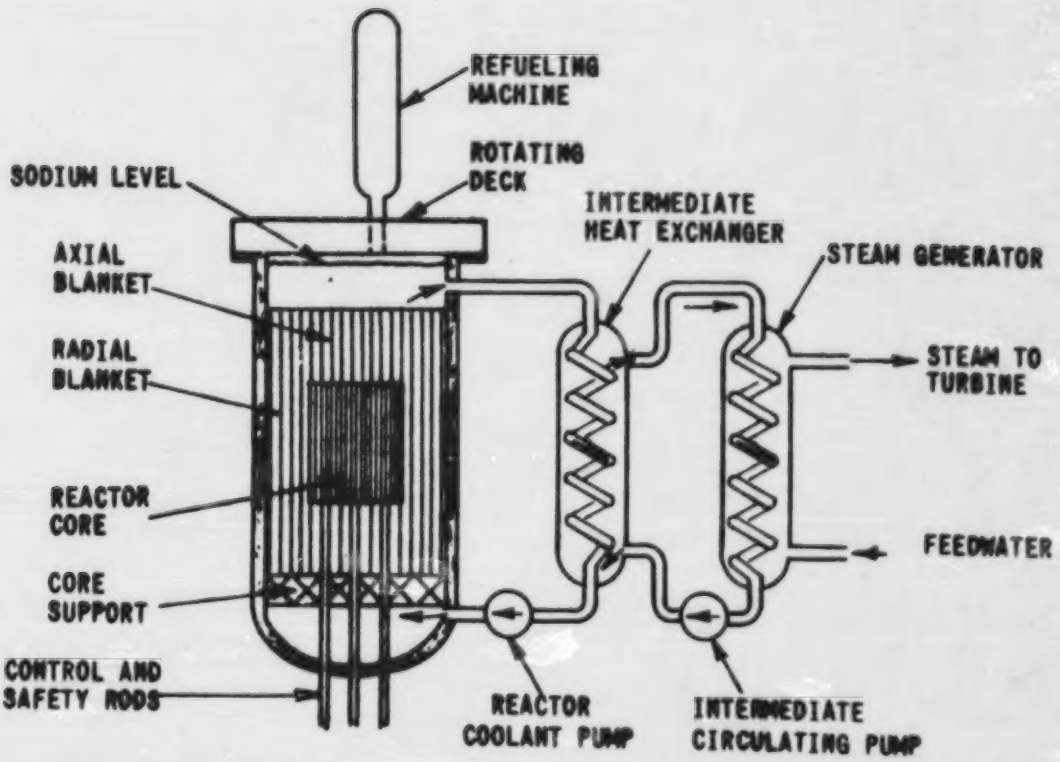


HIGH TEMPERATURE - GAS COOLED REACTOR WITH STEAM CYCLE

FIGURE 3.14



HIGH TEMPERATURE - GAS COOLED REACTOR WITH COMBINED CYCLE
FIGURE 3.15



LIQUID METAL FAST BREEDER REACTOR

FIGURE 3.16

3.3 NUCLEAR FISSION - (Cont'd)

Even though inexpensive fertile material is the major fuel component, breeder reactor fuel reprocessing costs are high, therefore the fuel cycle will be at least as costly as the Candu type.

A 250 MW Phenix LMFBR began operation in France in January 1974, and a 400 MW LMFBR is planned for start up in 1982 at Clinch River, Tennessee. Energy Research and Development Administration has scheduled a construction start on the first commercial LMFBR in 1986-87 (Ref. 30).

High temperature gas cooled fast breeder reactors (GCFBRs) will use much the same technology as the gas cooled non-breeder reactors discussed in Section 3.3(d). The inert helium coolant will need to be pressurized to provide a similar heat transfer rate as liquid sodium in the LMFBR, but does not moderate the breeding reaction and therefore has a higher uranium efficiency. The reactor core of the GCFBR will be very similar to the blanketed core of LMFBR.

No GCFBRs have been commercially developed to date, but combining the technologies of the HTGCR and the LMFBR will allow fast development. Capital costs are very speculative and in the energy summary (Table 1-1, located at the end of the report) have been assumed similar to the HTGCR. Fuel costs have been assumed similar to the LMFBR.

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SECTION 4.0 - NON-CONVENTIONAL RESOURCES

The non-conventional sources of energy with potential for power development are nuclear fusion, solar, tidal, geothermal and solid waste. Included in the solar energy resource system are space and water heating, thermal-electric generation, photovoltaic generation, organic farms, wind energy, ocean thermal gradients and wave energy. Ocean currents are discussed under tidal energy (along with barrage schemes) because the fast flowing currents off the B.C. coast are generally tidal currents and not thermal currents.

Many of the non-conventional technologies are only adaptable to certain geographic regions within the province, and might only economically supply small quantities of intermittent power. A reliable central power system will be necessary if full advantage is to be taken of these technologies.

4.1 NUCLEAR FUSION

Nuclear fusion is the energy process which occurs in the sun and ultimately provides the earth with its solar energy. Temperatures of 100 million ^{o}C are necessary before two or more nuclei can fuse together, usually to form one neutral helium nucleus plus a neutron. As with the fission reaction, a small fraction of the reacting mass disappears and is converted into energy according to the relationship $E = MC^2$.

The energy sources for this reaction are deuterium (one neutron and one proton), and tritium (two neutrons and one proton). The deuterium-tritium (D-T) reaction is the fusion reaction which has the best chance of technical realization today. Deuterium can be

extracted from seawater. It naturally occurs as one atom per 6500 normal hydrogen atoms in all water. The oceans thus offer an almost limitless source of deuterium. Until a deuterium-deuterium (D-D) reaction is developed, tritium will be the limiting source of fusion energy. Natural tritium is very rare, however it can be bred from lithium which is the 15th most common element in seawater. The known energy available from deuterium is 4×10^9 Q with another 4×10^9 Q estimated as discoverable. Tritium known reserves are 3×10^6 and discoverable reserves are estimated at an additional 3×10^6 Q. (Ref. 1, Volume 1, page 14.) Eventually, the limiting factor for fusion energy production may be structural material for the reactors.

Because of the astronomically high temperatures involved in fusion reaction, conventional metal-walled vessels will conduct heat away from the reaction too fast. Instead, "magnetic bottles" have been proposed which will contain the ionized hot plasma within evacuated magnetic fields. Various sorts of magnetic field geometries are currently being studied, all of which are designed to squeeze and heat the deuterium fuel long enough for the thermonuclear reaction to ignite. Fuel can be injected into the magnetized vacuum chamber either by means of a particle accelerator at velocities approaching the speed of light; or by subjecting a small pellet of deuterium-tritium fuel to the concentrated energy of a powerful laser beam which would explode the pellet and momentarily generate sufficiently high pressures and temperatures at the centre of the pellet to allow the fusion reaction to ignite. Using either system, the fast neutrons produced in the reaction can be absorbed directly by a heat collecting system which would power a conventional steam-electric generating system with an overall efficiency of 50 percent (Ref. 2). If liquid lithium is used as the reactor coolant, additional tritium will be produced as a normal by-product of reactor operation.

4.1 NUCLEAR FUSION - (Cont'd)

The fusion process may provide additional benefits over fission reactors because the fuel is non-radioactive and non-polluting as well as being inexpensive and virtually inexhaustible.

Predicting a date for commercial availability is very speculative as the physics of gases at high temperatures is not perfectly understood. Optimistically, D-T fusion reactors may be available by the year 2000 (Ref. 1, Volume III and Ref. 3, page 58); more realistically though it will be 2050 (Ref. 1, Volume III). A 500 MW demonstration reactor is planned by the Energy Research and Development Administration in the U.S.A. in 1997. A Tokamak Fusion Test Reactor is currently being built in Princeton, New Jersey. This $228 million experimental fusion reactor is scheduled to begin operation in 1981. It will be the world's first unit designed to produce significant amounts of thermonuclear energy. No date has been predicted for the first deuterium-deuterium reactors.

In the summary, Table 1.1, capital costs of fusion reactors have been very speculatively assumed the same as for LMFBRs (Ref. 4) and fuel costs essentially zero.

4.2 SOLAR ENERGY

Solar energy provides the largest continuous resource system available. Fusion of hydrogen nuclei to form helium in the sun gives energy to warm the earth, develop winds, ocean currents and hydrological cycles and produce food and fuel. There is approximately 5000 Q/yr of energy radiated to the earth's outer atmosphere and its distribution is shown in Fig 4.1.

Most forms of solar energy are abundant, diffuse and sporadic. Solar energy power systems are characterized by high initial

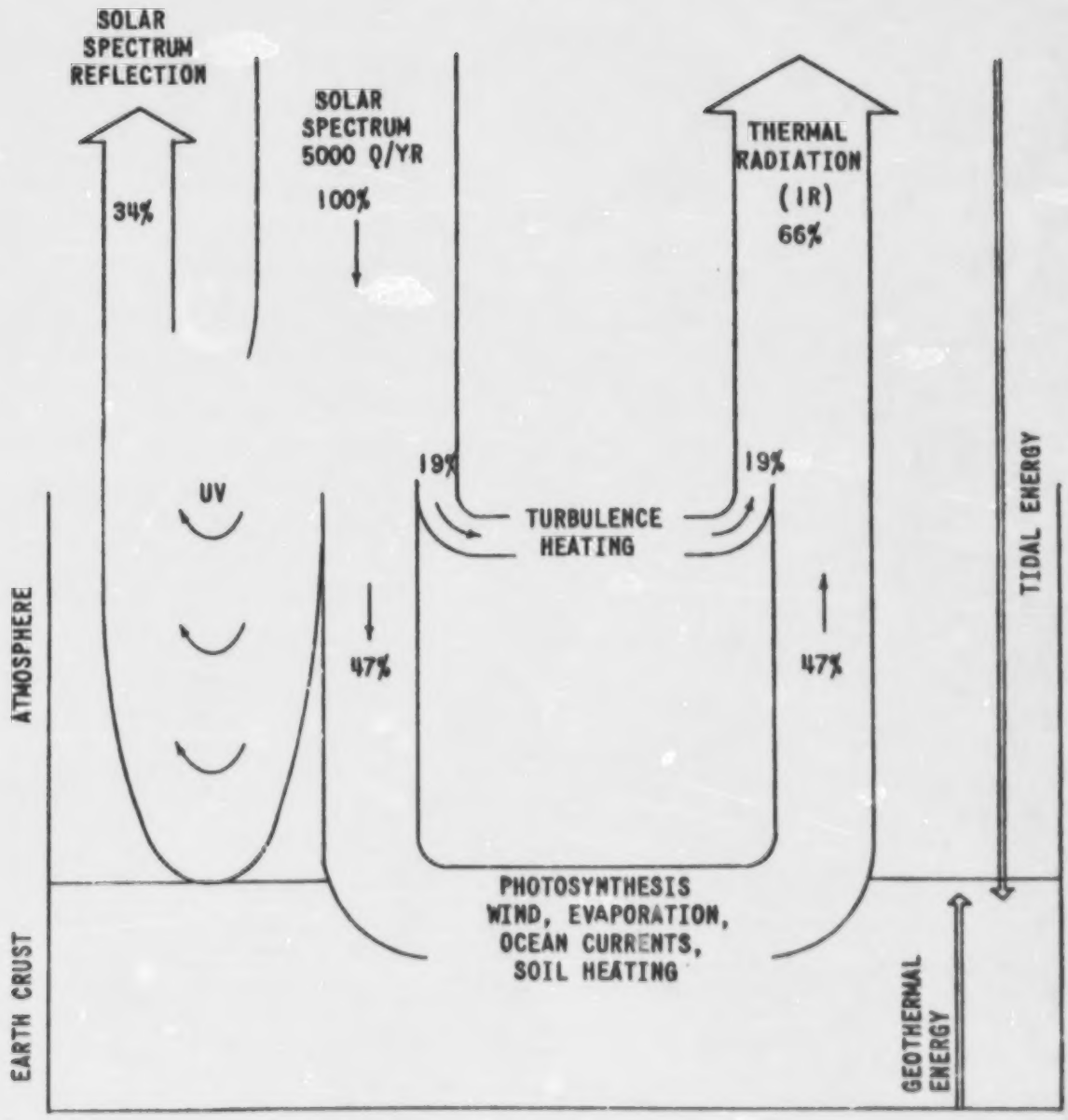
4.2 SOLAR ENERGY - (Cont'd)

investments and low conversion efficiencies. Whether used for power generation or not, solar energy is transformed to heat, therefore solar energy power generation does not add to the earth's heat load. However, the total amount of energy which can be re-routed for power generation in Fig. 4.1 without disturbing the flow balance may eventually limit the power recoverable. Also, the localized effects of thermal pollution must still be considered as is the case with fossil fuel plants.

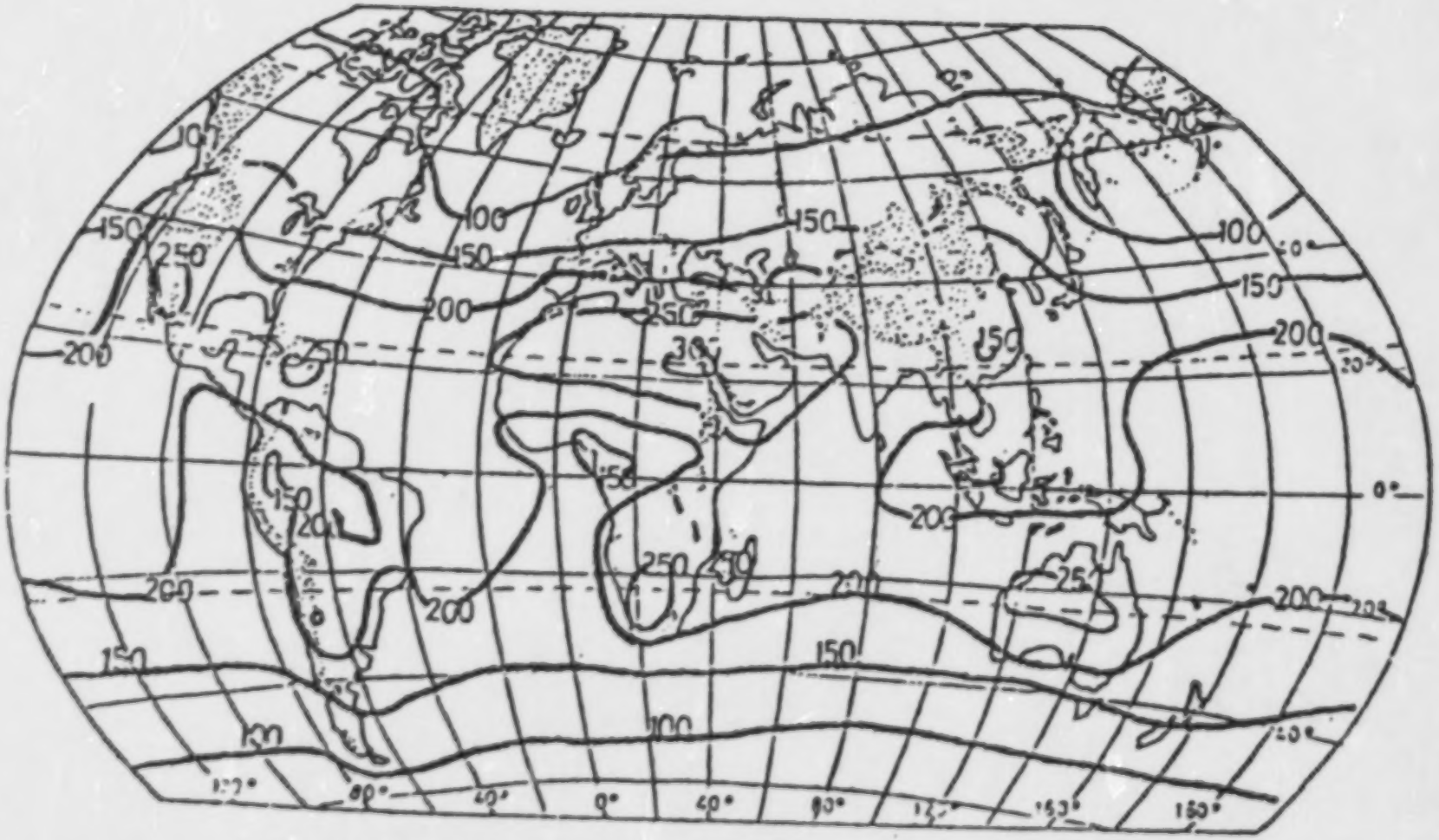
(a) Solar Radiation

2400 Q/yr reaches the earth as solar radiation. The density varies with latitude, climate, season and time of the day and Fig. 4.2 indicates the annual average energy input from radiation around the world. In B.C. the annual average radiation energy varies from 3.9 kWh/m^2/day in the southeastern part of the province to 2.6 kWh/m^2/day in the northwest. Vancouver receives 3.5 kWh/m^2/day (Ref. 3). Comparatively, Tucson, Arizona, receives 5.5 kWh/m^2/day (Ref. 4). Monthly average radiation for various locations in B.C. and for Tucson, Arizona are shown in Table 4.1. The monthly variation in B.C. is far greater than for preferred solar energy installation areas such as Tucson.

Average radiation figures are a total of diffuse (or reflected and refracted) light and beam (or direct) light. In B.C., about 45 percent of the radiation is diffuse during the summer months and 70 percent is diffuse during the winter. Because diffuse radiation from the sun does not appear to come from a specific source, it cannot be optically concentrated.



SOLAR ENERGY FLOW
FIGURE 4.1



ANNUAL MEAN SOLAR ENERGY (WATTS PER SQUARE METER AVERAGE OVER 24 HOURS)
FIGURE 4.2

TABLE 4.1

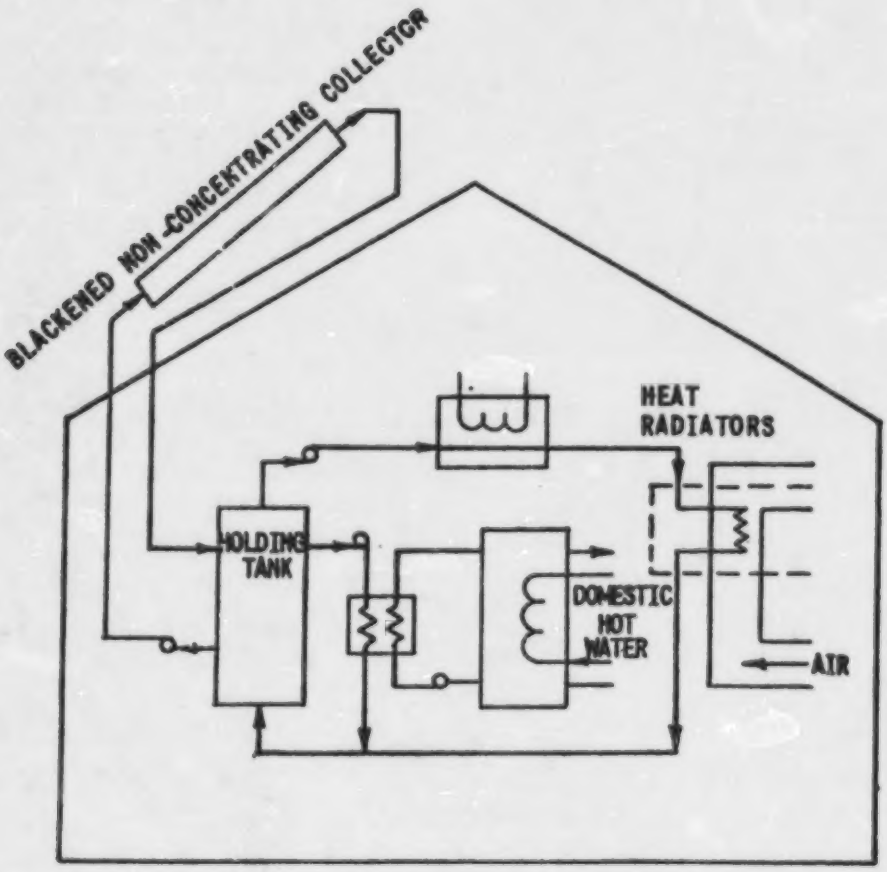
MONTHLY AVERAGE SOLAR RADIATION
($kWh/m^2/day$)

	J	F	M	A	M	J	J	A	S	O	N	D
Vancouver (Ref. 11)	.81	1.64	2.83	4.16	5.76	6.02	6.41	5.24	3.66	2.01	.98	.63
Summerland (Ref. 11)	.95	1.78	3.21	4.63	5.83	6.29	6.58	5.58	3.95	2.19	1.07	.70
Kamloops (Ref. 11)	.83	1.80	2.92	4.44	6.00	6.14	6.71	5.59	3.83	2.16	1.06	.65
Ft. Nelson (Ref. 11)	.51	1.23	2.72	4.34	5.61	5.36	5.67	4.62	2.80	1.58	.63	.30
Tucson, Arizona (Ref. 7)	3.50	4.39	5.52	6.95	7.68	7.72	6.91	6.11	5.47	5.01	3.85	2.74

Solar radiation can be harnessed to supply the energy requirements of man by using space and water heaters, thermal-electric generating stations or photovoltaic generating stations.

(i) Space and Water Heaters

Space and water heaters powered by solar energy are used extensively in Australia, Israel, Japan and the U.S.A., but have limited use in Canada. A blackened non-concentrating collector, usually mounted on a roof top, absorbs the sun's shortwave radiation (Fig. 4.3). Water is circulated through copper tubes, over corrugated metal, or through evacuated glass tubes to cool the blackened surface. One or more transparent covers are placed over the collector to prevent re-radiation of the heat. Water temperatures of 100°C may



SOLAR HOME HEATING SYSTEM
FIGURE 4.3

be achieved for a few hours a day in Canadian locations. The hot water is transferred from a large holding tank to a radiating system when required for heating.

The energy intake from this system is dependent on the collector area and the ambient temperature of the air. Cold temperatures and low radiation densities during the winter months in Canada necessitate uneconomically large collector areas to provide year round heating, therefore a back-up heating system must also be provided and the space and water heating system evaluated as a fuel saver. B.C. Hydro has experimented with solar heating systems, and current indications are that about 40 percent of the total space heating requirement may be displaced by the solar heating system. The capital costs for solar space heating are of the order of $20,000 to $25,000 per home, which results in a unit heating cost which is over one order of magnitude greater than the cost associated with conventional energy sources.

Collector mass production may reduce costs substantially in the next 5 to 10 years so that solar space and water heating becomes competitive with fossil fuel heating. Design plans for new homes should consider this possibility and owners of older homes might consider retro-fitting. The legal and planning problems of collector shading will also need consideration.

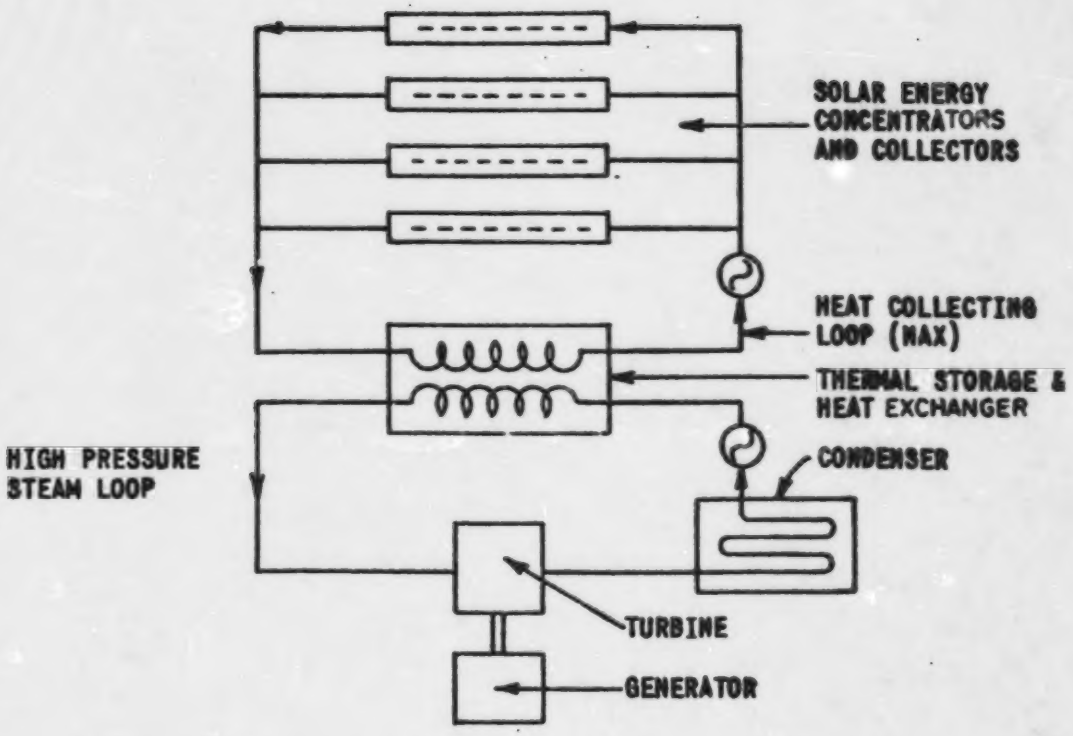
Hot water collectors are able to supply economic domestic hot water in B.C. and one particular advantage is that hot water is still used during the

summer months. Using about 100 feet^2 of collector surface to heat incoming cold water will provide up to 80 percent of the hot water requirement of an average home at about $1200 capital cost per home. The cost of electrical energy saved would equal 8 percent annual charges on the collector system and relative benefits will improve as collector costs decrease and home heating fuel costs increase (Ref. 15).

(ii) Thermal Electric Generation

Concentration of solar radiation to heat water to temperatures of over 500^{o}C may provide a commercial source of energy for electric power generation (Fig. 4.4). One conceptual design plans to focus the beam radiation onto a central tower receiver using heliostats which can track and reflect the sun (Ref. 16). Thermal energy storage using molten salts to provide 3 to 6 hours storage will allow steam-cycle power generation to follow the daily load cycle at a 40 percent capacity factor. The overall efficiency will probably not exceed 20 percent. (Ref. 7, page 11-12.) More elaborate systems electrolyse water to produce hydrogen which can then be stored for base load fuel cell power generation. Higher efficiencies will require high quality concentrating devices which have not shown any possibility of economic production to date.

A 10 MW central receiver - heliostat pilot plant is scheduled for operation in 1980, a 100 MW demonstration plant in 1985 (Ref. 17) and a 5000 MW commercial facility may operate after 1995 in the



SOLAR THERMAL ELECTRIC SYSTEM
FIGURE 4.4

southern U.S.A. (Ref. 18). Capital costs for the commercial plant will probably be between $1000/kW (Ref. 1, Volume I, Fig. 4.5-1) and $2500/kW (Ref. 2, page 69) installed and require about 10 square miles per 1000 MW in the U.S.A. (Ref. 17, page 57).

In B.C., because winter radiation levels are extremely low and because the incoming energy is primarily diffuse, thermal-electric power generation possibilities are limited. Vancouver land requirements would be at least 2 acres per GWh per year and north-eastern B.C. would require at least 3 acres per GWh per year. The actual land use could be up to 3 times this to prevent collector shading, however multiple land use might be possible. If the central receiver concept is developed, the land required need not be flat. Capital costs would be between $3000 and $7500/kW, or three times those required for southern U.S.A. locations (Ref. 19, page 35). The cost for electricity would be between 10 and 25 times more expensive than conventional sources in B.C., primarily because generating capacity installed to convert high summer daytime energy inputs is left idle for most of the winter.

(iii) Photovoltaic Generation

Photovoltaic solar cells are capable of converting incoming solar radiation directly to electric power. Photons penetrate the cell and cause an electrical potential to develop across a semi-conducting p-n junction. Current flows when an external circuit is

connected. The theoretical maximum efficiency of conversion is 23 percent, however, 20 percent is the highest efficiency achieved in ideal laboratory conditions.

A trade off will have to be made between efficiency and cell production costs. High efficiency single-crystal cells currently cost from $10,000 to $75,000/kW peak. Batch processing of thin film poly-crystalline cells with 10 percent efficiencies and optical concentration of the incoming radiation may reduce the costs.* The ERDA goal is $500/kW peak and 500 MW capacity delivered in the U.S.A. by 1986 (Ref. 13, page 56) and $100/kW peak by 1995 (Ref. 24).

The cost of cells, usually quoted in $/kW peak, assumes input radiation of 1 kW/m^2. Cost calculations by A. Fort of the National Research Council, reproduced in Ref. 24, estimate capital costs at $950/kW rated ($784/kW in $1974) operating at 15 percent efficiency and a 42 percent capacity factor in a location with similar solar insolation as southern B.C. and using 1995 predicted cell costs of about $100/kW peak. Using today's cell costs of at least $10,000/kW peak indicate system costs of about $25,000/kW rated. Land requirements will be about 4-6 acres/GWh per year depending upon the B.C. location chosen (assuming 10 percent overall efficiency and only beam radiation available for conversion).

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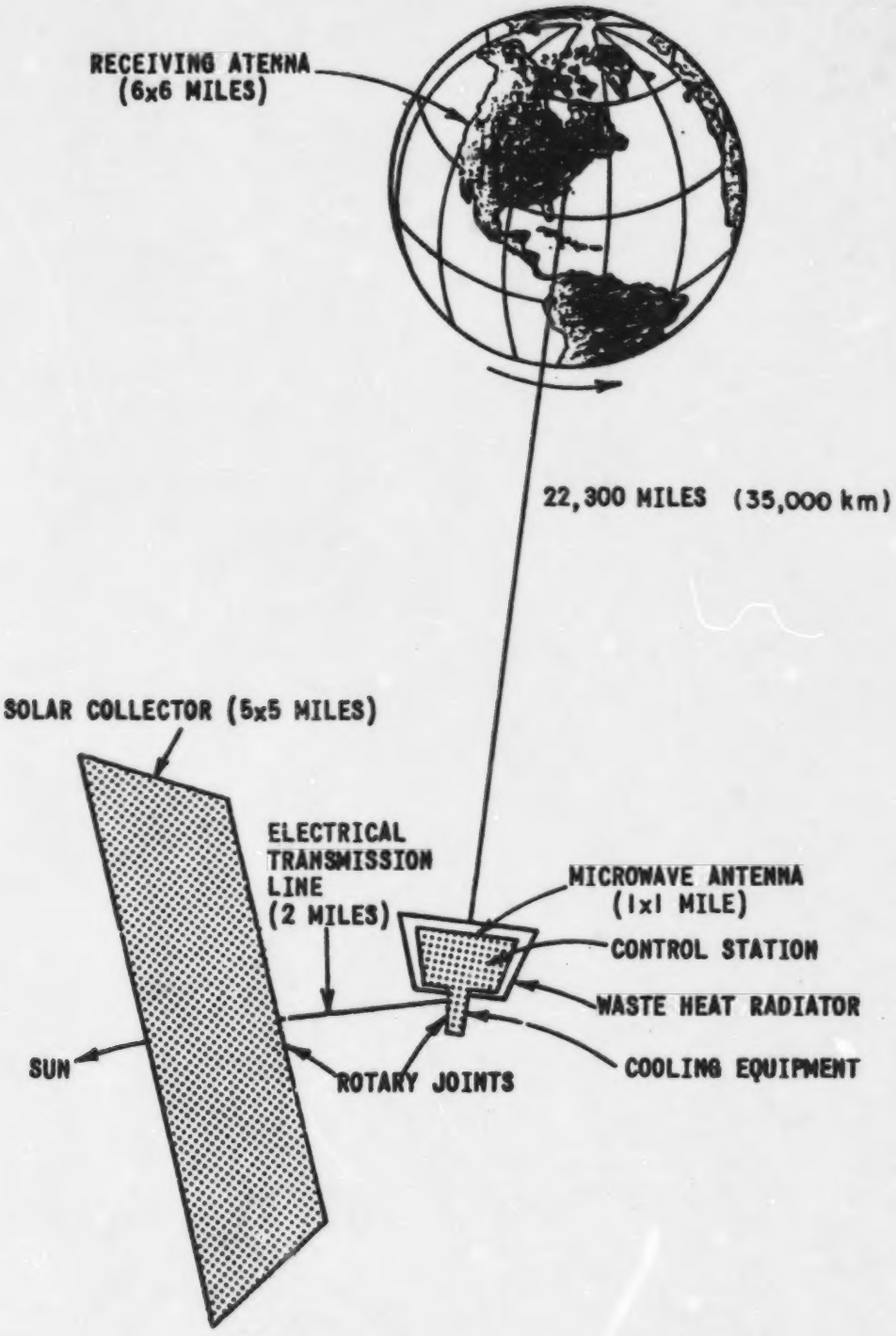
* Optical concentration of light will only allow beam radiation to be used.

Peter Glaser of A.D. Little, Inc., has proposed that large arrays of photovoltaic cells launched into a geosynchronous orbit 35,000 km from earth could, with sunshine 24 hours a day and no cloud cover or atmospheric reflection, provide a continuous energy source (Fig. 4.5). Such a scheme would convert the radiant energy directly to electricity with its photovoltaic cells, then transform the electrical energy to microwave for high efficiency (90 percent) power transmission through the clouds and atmosphere to a large receiver on earth. The total efficiency of the transmission and collection facilities might reach 77 percent (Ref. 1, Volume II, Table 14.7-2) giving an overall efficiency of about 8 percent including photovoltaic cells. Launching energy efficiencies are questionable and today's launching costs account for the majority of the $400,000/kW capital investment. If the launching costs are reduced, optimists project capital costs of only $350/kW (Ref. 1, Volume II, page 371). Land use on the earth will be only 0.3 acres/GWh/yr if microwave densities proposed in Fig. 4.5 prove safe. Technically, a subscale orbital demonstration plant could be operating by 1985. (Ref. 17, page 57.)

(b) Organic Farms

The sun's energy may be photosynthetically converted to electricity at an overall efficiency of less than 1/2 percent of the annual sunlight. Plants such as sugar cane, sunflowers, soy beans and alfalfa may produce 7500 Btu's per pound of dry material harvested. This can be burned to provide heat for electric power generation or heated in an oxygen deficient environment (pyrolysis) to produce gaseous and liquid hydrocarbons.



10,000 MW. SATELLITE SOLAR POWER STATION
FIGURE 4.5

4.2 SOLAR ENERGY - (Cont'd)

For the Pacific northwest region, red alder has been proposed as a fuel source. Calculations indicate that 416,000 acres would supply fuel for a 150 MW generating station, or approximately 50 acres of land per GWh (Ref. 25). In other areas of B.C. land use may be up to 15 times that required in the Pacific northwest. Considering that most crops have a $200/acre yield, to be competitive the red alder must have a 10 mills/kWh fuel charge. Capital costs of a wood burning plant should be comparable to coal burning plants, making the photosynthetically derived electricity only slightly uneconomic. Although the technology for harvesting and producing electricity are available today, possible problems such as soil nutrient depletion and disease in a monoculture cultivation require assessment.

Hog fuel, a natural residue of the forest product industry, is burned to produce steam and electricity at some pulp and paper mills. The availability of this resource and the cost of transportation presently inhibit its use at power generating stations. Only in the Cariboo, Prince George, Skeena-Bulkley and Peace River regions is a surplus shown which might provide a few 30 to 60 MW generating stations (Ref. 26). A more practical use of hog fuel would entail total use by the pulp and paper industry and sale of excess electricity to power companies.

Algae and kelp have also been proposed as an energy biomass, having the advantage that ocean surface area is less valuable than land. Harvesting and dewatering processes have not been developed yet which might make this proposal economic. A euphorbia genus of plant (similar to a rubber plant) is also known to produce a latex similar to crude oil. Conversion efficiencies and land use requirements for this possible energy source are unknown.

4.2 SOLAR ENERGY - (Cont'd)

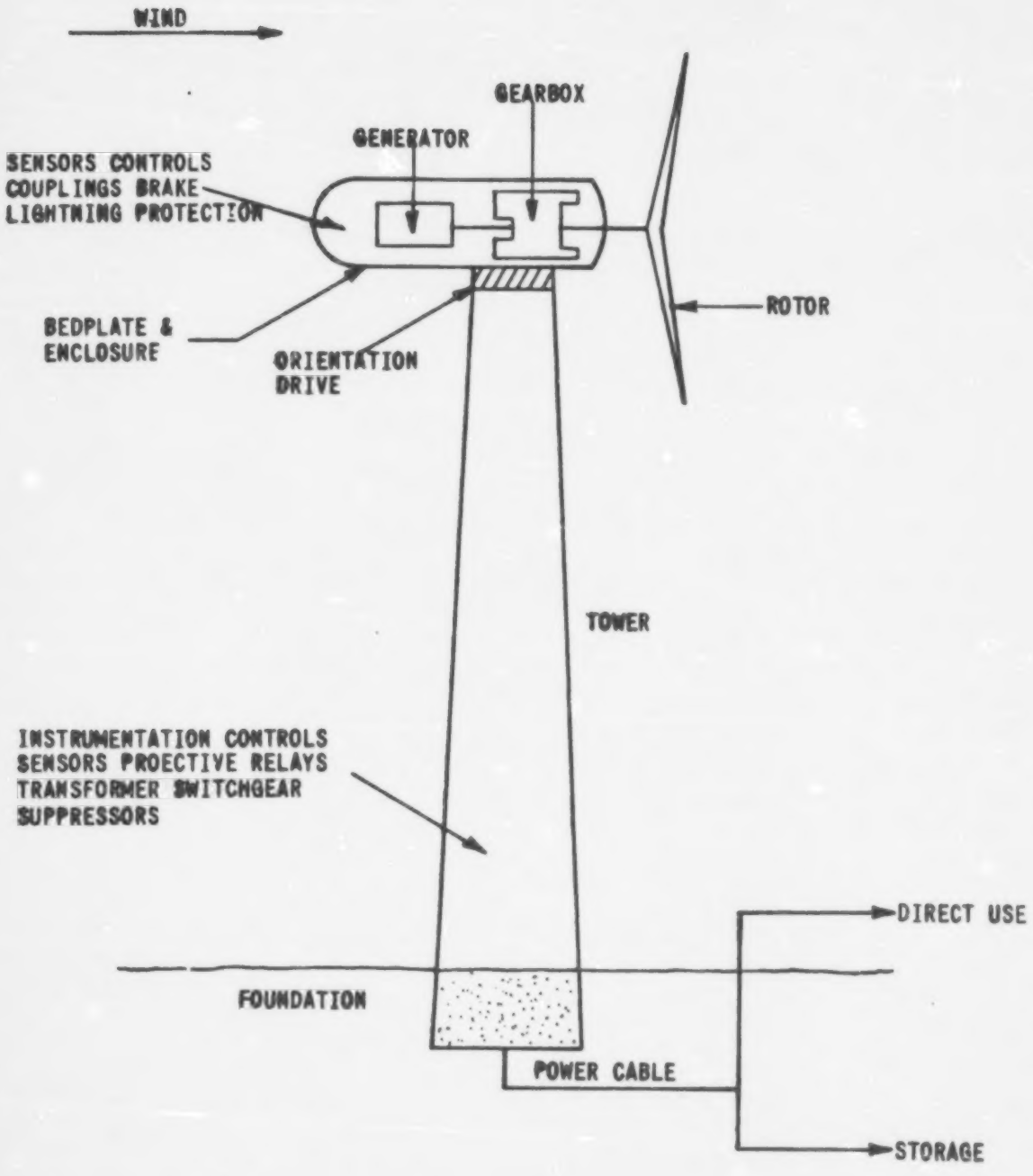
(c) Wind Energy

About 2 percent of the solar radiation reaching the earth's surface is converted to wind energy, 1 Q/yr of which is considered usable. It is invarient (does not add to the earth's heat load), renewable and has zero fuel cost. Previous uses include power for ships, homes, industry and agriculture. In Nigeria, Australia and India it is used to pump water; in Indonesia and Norway, rural electrification; and in Uruguay, main grid electrification.

Among the wind driven generator (WDG) designs considered so far are 1, 2 or 3 bladed propellers, Darrieus vertical axis windmills and savonius rotor windmills. In the U.S.A., development of propeller designs as in Fig. 4.6 has been the choice to date for large scale wind generators. Cost-effectiveness studies indicate that single counter-balanced blades and two bladed propellers will eventually prove the best (Ref. 30, page 23). Canadian development has been guided towards smaller vertical axis generators.

Operating experience with large WDGs began in 1941 in an area called Grandpa's Knob, near Rutland, Vermont. A 1.25 MW Smith-Putnam WDG operated for 4 years before blade failure caused a shutdown. In September 1975, a 100 kW WDG began operation at NASA's Plum Brook Station, near Sandusky, Ohio. A number of designs for 1.5 MW units are now also complete. Five to six MW units are expected to be developed (Ref. 30).

B.C. Hydro has had two 2 kW bladed WDGs in operation, one at Carson Mountain near Clinton and the other at Masset on the Queen Charlottes. Vandalism and blade failure caused these to be shut down.



WIND DRIVEN GENERATOR

FIGURE 4.6

4.2 SOLAR ENERGY - (Cont'd)

The power theoretically available from a bladed WDG is:

$$P = \frac{2.36}{10^6} D^2 V^3$$

P - horsepower
D - blade dia. (ft)
V - free stream wind velocity (mph)
(Ref. 31)

The proportionality of the power to the cube of the velocity indicates the importance of location selection. The theoretical efficiency is 59 percent (Ref. 1, Volume II, page 419) of the energy contained in the wind. Actual efficiencies will probably range from 35 percent (Ref. 7, page 11-8) to 40 percent (Ref. 29, page 872). Capital cost estimates vary from $500/kW for mean wind speeds in excess of 18 mph to $850/kW for 12 mph mean wind speeds. (Ref. 29.)

Additional operating costs will be incurred for energy storage if an integrated electricity grid with a large storage potential is not included in the planning. If compressed air, pumped water, batteries or hydrogen storage are used (Section 5.0) variable propeller speed will be possible*, partially offsetting the efficiency losses of the storage. Variable pitch propellers may also be necessary for start-up periods in low winds and feathering in high winds.

Coastal locations appear to have the best Canadian potential for WDGs. The prairies and the Arctic also show some promise. Average yearly wind velocities for B.C. and Canadian locations are shown in Table 4,2. Clearly, few locations are

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* Constant speed propellers are proposed on present designs to allow 60 Hz power generation.

4.2 SOLAR ENERGY - (Cont'd)

available with wind velocities averaging over 18 mph, which is considered an economic cut-off for large scale power generators. (Ref. 30.)

TABLE 4.2

AVERAGE YEARLY WIND
(Ref. 32)

Location	Year Average (mph)
Abbotsford	6.7
Cape St. James	21.2*
Bonilla Island	18.2
Comox	7.4
Ft. St. John	10.8
Ft. Nelson	4.7
Kamloops	7.3
Prince George	7.2
Prince Rupert	9.0
Tofino	8.0
Vancouver	7.5
Edmonton, Alberta	9.2
Saskatoon, Saskatchewan	11.2
Winnipeg, Manitoba	12.0
Ottawa, Ontario	9.4
Gander (Nfld.)	13.0

* Wind on B.C. coast is characterized by 100 mph gusts (blade failure).

Large scale wind power development will be characterized by high land use. On Vancouver Island, to provide the energy equivalent of a 600 MW nuclear power plant would require over 160 square miles of land (or 25 acres/GWh) and 2800 miles of transmission cable (Ref. 19, page 34, based on 10 mph wind velocity, 50-foot diameter blades and 300-foot spacing). Of couse, multiple land use is definitely a possibility. The potential of large generation systems in windy areas must be evaluated with regard to system interfacing, storage and fuel saving capability. Commercial generators may be available

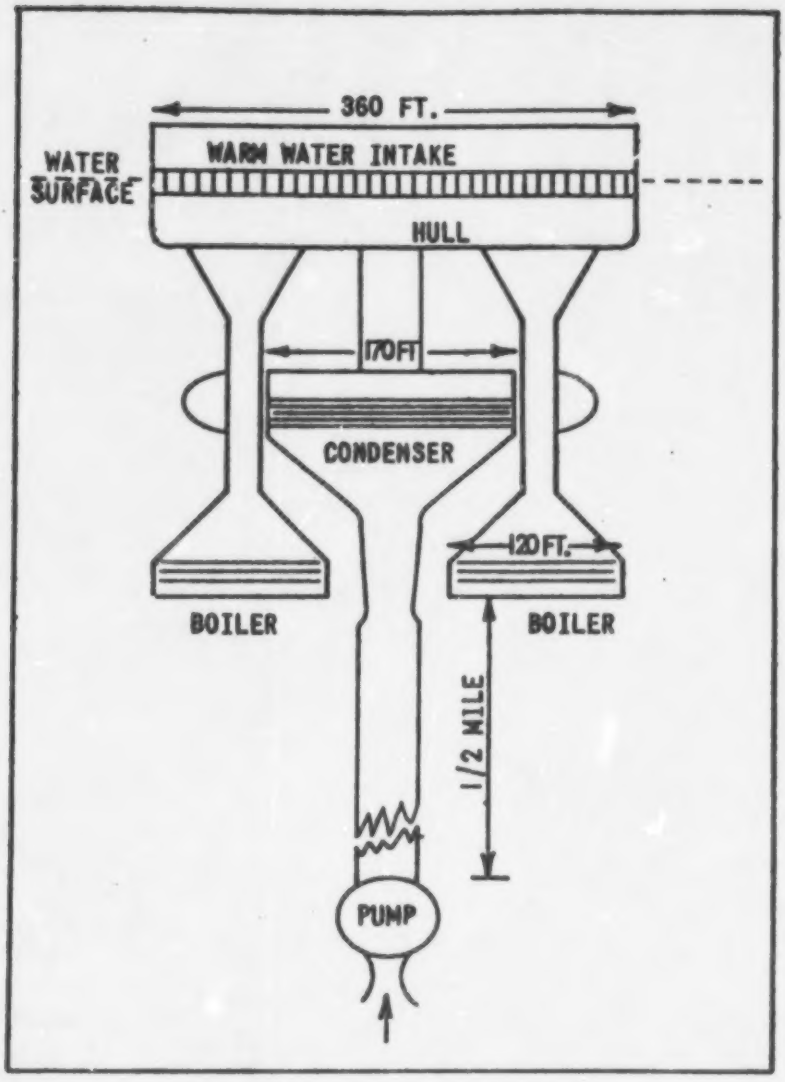
during the period of 1980 to 1985. Additional consideration must be given to aesthetics, safety precautions against blade failure, and drafts and noise from the spinning propeller.

Isolated power generation may have an advantage in remote windy areas, depending on the cost of conventional power in that area. In some cases a 12 mph (average) wind regime may be sufficient to develop economic power from WDGs now commercially available in sizes up to 10 kW. The vertical axis generators being developed in Canada may find cost advantages over bladed generators of this size. A 200 kW Darrieus generator being constructed by Dominion Aluminum Fabricating Co. of Toronto may sell for only $500/kW whereas bladed generators are closer to $1000/kW (Ref. 24).

(d) Ocean Thermal Gradients

A potential for power generation exists in the difference between ocean water temperatures (ΔT) on the surface and at depths of a few thousand feet. Conceptual designs to harness thermal gradients, as shown in Fig. 4.7 involve pumping large quantities of cold ($4^{o}C$) water up to the floating generating plant. Warm surface water would heat a working fluid (ammonia, propane, freon or isobutane) and a vapour cycle would be used to develop power with the cold deep ocean water functioning as the recoolant.

Theoretical calculations for the potential of the Gulf Stream indicate it might provide 0.1 Q/yr if fully developed (Ref. 1, Volume II, page 374). Using $27^{o}C$ surface water, a 3 percent (Ref. 7, page 11-25) overall efficiency is probable and capital costs are expected to range from $725 to $2200/kW. (Ref. 1, Volume II, page 395.) Electrical transmission costs from



OCEAN THERMAL GRADIENT POWER SCHEME
FIGURE 4.7

such installations will probably be prohibitive, and may warrant electrolytic conversion to hydrogen for transportation. The environmental aspects of removing thermal energy and discharging cold water at the ocean surface have not been studied, but cultivation of marine food may be possible with the nutrient rich cold water. Technical problems may also develop in trying to produce a pumping system capable of handling millions of gallons of surface water per minute per 100 MW..

The potential of B.C.'s coastal waters is very small. The gross power available from ocean thermal gradients is proportional to ΔT^3 and the cost is proportional to ΔT^{-3}. (Ref. 1, Volume III, page 396.) With 13°C surface temperatures and 4°C bottom temperatures, the costs will be 15 times those expected for Gulf Stream installations.

In the Canadian Arctic a potential exists to employ this technology using the temperature difference between unfrozen ocean water and cold arctic air. Feasibility and cost data are not available.

One benefit which may develop from ocean thermal gradient technology is an economic bottoming cycle. The rankine cycle, with the proper working fluid, might extract an additional 10 percent (Ref. 1, Volume II, page 400) of the power output of an ocean based thermal plant by using the sea water for cooling.

(e) Wave Power

Waves are caused by the wind acting on the ocean surface and are therefore a renewable energy source. The total resource is approximately .075 Q/yr (Ref. 1, Volume II, page 465). However, only a fraction of this might be considered harnessable.

4.2 SOLAR ENERGY - (Cont'd)

Wave power has been used in the past for air column excitation and bell-clapping in navigational aids. Conceptual designs for possible future power generation include harnessing either the vertical or the horizontal motion of waves. Among schemes considered is one to provide pressurized air for electricity generation or hydrogen production from the vertical motion. The efficiency of such a scheme might approximate 40 percent. Another system utilizes the horizontal motion of the waves by movement of the pear shaped device. A number of these devices connected to a pumping mechanism might capture 66 percent of the wave energy (Ref. 24).

Capital costs of wave power generators are very speculative, but might range from $1000 to $2000/kW (Ref. 24). As with wind power, site selection will be very important and transmission costs may be prohibitive. On-site hydrogen production and storage may negate transmission costs and allow the generating stations to drift freely from deep, rough water into the shore. The stored hydrogen would then be unloaded and the stations returned to high energy locations. Environmental and navigational problems may develop as most plans project strings of equipment miles long.

For the Strait of Georgia, after 10 hours of wind at 20 knots the waves reach about a 5 foot amplitude with a period averaging 8 seconds and a wavelength of 90 feet. At Cape Scott on the northern tip of Vancouver Island, Pacific swells from 6 to 12 feet and wind waves from 5 to 8 feet reinforce each other to give waves which may reach 24 feet for 15 percent of the time. The Pacific weather ship which is a few hundred miles off shore, reports waves as large as 60 feet. (Ref. 40.)

4.2 SOLAR ENERGY - (Cont'd)

Assuming a location with 10 feet combined swell and wind waves, a 100-foot wavelength and a 10-second period, the energy potential is about 5 kW* per foot parallel to the wave front. (Ref. 1, Volume II, as per Equation 16.8-4.) If 66 percent of this energy could be harnessed at a 60 percent capacity factor a 1-mile string of wave generators parallel to the wave front direction might produce about 65 GWh/yr. A 1000-mile string along the B.C. coast might produce 2.3×10^{-4} Q/yr.

4.3 TIDAL ENERGY

The gravitational pull of the moon and sun cause water elevations of major bodies of water to change and fast currents to flow between constricting points of land. The period of oscillation is consistently about 12 hours but the strength of the tides varies from oscillation to oscillation. Almost 9×10^{-2} Q/yr is dissipated as renewable tidal energy throughout the world.

(a) Barrage Schemes

Tidal ranges are amplified near shores because of decreasing water depth, and may be further amplified in bays or estuaries to over 10 meters by a resonance effect. Power can be developed by constructing a barrage to force the water flowing into or out of a basin through a turbine. To overcome the time dependence of power outputs from such a scheme, multiple basins may be developed with interconnecting reversible turbines and/or low head pumps. High head pumped storage might also be used to overcome the time dependence. Alternately, tidal power schemes could be tied into an integrated electrical system having large energy storage capability.

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* Ref. 24, page 147, indicates average west coast waves are approximately 5 1/2 kW/ft.

4.3 TIDAL ENERGY - (Cont'd)

Environmentally, barrage schemes have the potential to affect fisheries, tidal-current patterns and siltation, and might aggravate existing pollution problems. They have no waste products and no thermal or air pollution. Capital costs can range from $800/kW (Ref. 1, Volume II, page 460, escalated to $1976) to $1800/kW (Ref. 41, Shepody Bay 920 MW, $1.7 billion) and capacity factors of about 25 percent (Ref. 1, Volume I, Table 4.5) are expected. Cost reductions may be affected if a credit is attributed for using the barrage as a bridge and if technical advances are achieved with low-head turbines and barrage construction techniques.

The La Rance and the Kislaya Inlet developments in Table 4.3 are the only plants built to date. Other developments listed are only possibilities. About 1.9×10^{-3} Q/yr is considered technically developable world tidal energy, and recovery efficiencies of 10 to 25 percent (Ref. 1, Volume I, page 157) may allow collection of 4.3×10^{-4} Q/yr.

Although selection of the most advantageous scheme is specific to each development possibility, three factors are common:

1. High tidal range.

2. Large basin surface area.

3. Short barrage length necessary to enclose basin.

Observatory Inlet near Port Alice offers one of the best B.C. potential sites with an average tidal range of approximately 5 meters and a maximum range of about 8 meters. Comparative characteristics of Observatory Inlet and other potential sites

TABLE 4.3

TIDAL POWER LOCATIONS
(Ref. 1, Volume I)

Location	Average Range R, M	Basin Area S, kM^2	Average Potential (Total) Power P, 10^3 kW	Potential Annual (Total) Energy E, 10^6 kWh
North America				
Bay of Fundy				
Passamaquoddy	5.52	262	1,800	15,800
Cobscook	5.5	106	722	6,330
Annapolis	6.4	83	765	6,710
Minas-Cobequid	10.7	777	19,900	175,000
Amherst Point	10.7	10	256	2,250
Shepody	9.8	117	2,520	22,100
Cumberland	10.1	73	1,680	14,700
Petitcodiac	10.7	31	794	6,960
Memramcook	10.7	23	590	5,170
Subtotal			29,027	255,020
South America				
Argentina				
San Jose	5.9	750	5,870	51,500
Europe				
England				
Severn	9.8	70	1,680	14,700
France				
Aber-Benoit	5.2	2.9	18	158
Aber-Wrac'h	5.0	1.1	6	53
Arguenon & Lancieux	8.4	28.0	446	3,910
Frenaye	7.4	12.0	148	1,300
La Rance	8.4	22.0	349	3,060
Rotheneuf	8.0	1.1	16	140
Mont Saint-Michael	8.4	610	9,700	85,100
Somme	6.5	49	466	4,090
Subtotal			11,149	97,811
U.S.S.R.				
Kislaya Inlet	2.37	2.0	2	22
Lumbovskii Bay	4.20	70	277	2,430
White Sea	5.65	2,000	14,400	126,000
Mezen Estuary	6.60	140	1,370	12,000
Subtotal			16,049	140,452
GRAND TOTAL			63,775	559,483

throughout the world are listed in Table 4.4. Low ratios of barrage length to surface area and barrage length to energy are generally favourable, however, other factors such as the required height of the barrage also needs considerations. B.C. Hydro has allocated funds for an engineering overview of tidal power along the B.C. coast, but no development is planned for the near future.

(b) Ocean Currents

Both tidal ocean currents and thermal ocean currents have potential for power generation.

Most conceptual generator designs are bulb turbine-generators driven by a large propeller, as in Fig. 4.8 (similar to wind driven generators). One other possibility is the parachute design shown in Fig. 4.9.

The total developable world power from currents is estimated at 3000 MW (about 8×10^{-5} Q/yr). Along the B.C. coast, current flow is tidal and therefore reciprocates with approximately a 12 hour cycle. On a practical basis, only a small portion of the theoretical current energy could be harnessed. The total B.C. resource has been assumed 10^{-7} Q/yr in the summary. It is doubtful any major development funding could be provided for an energy source with this small a potential.

Capital costs for ocean current generators have been very speculatively estimated at $1450/kW (Ref. 4, $1200/kW in $1974). Impacts on ocean navigation and sea life have not been explored.

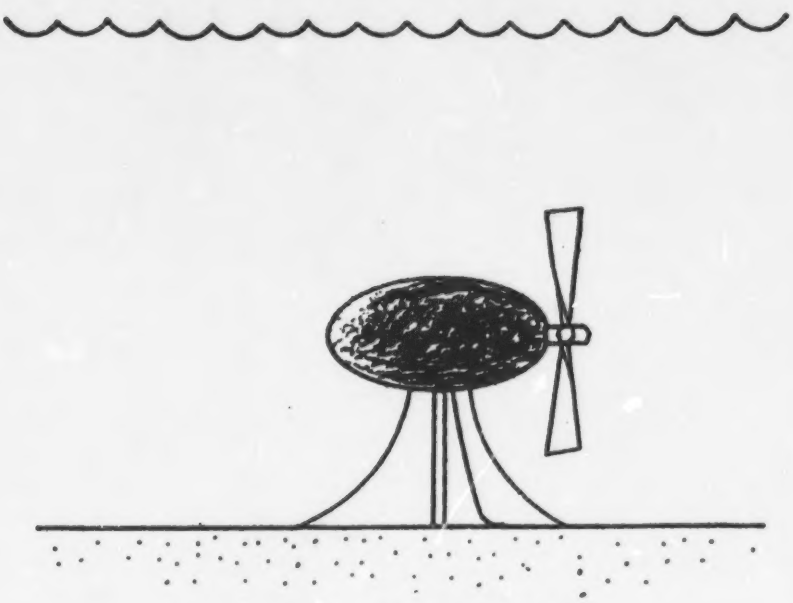
TABLE 4.4

TIDAL POWER SITES

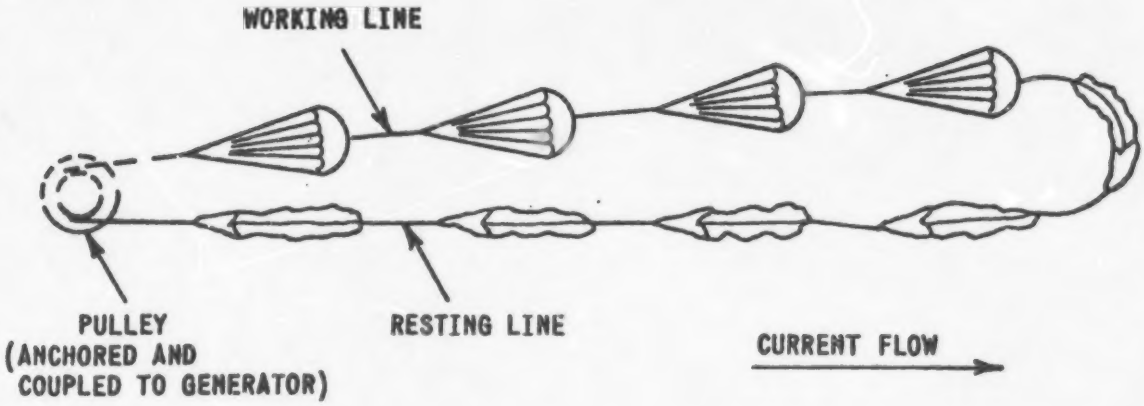
Source: Reference 1, Volume II (except, Observatory Inlet, B.C. Hydro & Power Authority)

Country and site	R Tidal range, m	S Basin area, km^2	E* Potential annual electrical-energy production, 10^6kWh/y	L Barrage length, m	L/S m/km^2	L/E $m/(10^6 kWh/y)$
France:						
Lorient	4.5	16.0	97	750	47	7.7
Brest	6.4	92.0	1,130	3,640	40	3.2
Alber-Benoit	7.4	2.9	48	200	69	4.2
Alber-Vrach	7.4	1.1	18	190	173	10.6
Arguenon and Lancieux	11.4	28.0	1,090	6,275	224	5.8
La Fresnaye	11.4	12.0	470	2,760	230	5.9
Rance	11.4	22.0	860	725	35	0.8
Rotheneuf	12.0	1.0	48	330	300	6.9
Chausey	12.4	610.0	28,140	23,500	39	0.8
Somme	9.3	49.0	1,270	5,100	104	4.0
United Kingdom: Severn	11.5	44.0	1,750	3,500	80	2.0
United States/Canada Passamaquoddy	7.5	120.0	2,025	4,270	36	2.1
Canada: Observatory Inlet	4.7	212.0	1,405	2,400	11.3	1.7

* Calculated on the basis: $E \simeq (0.3 \times 10^6) R^2 S$



BULB CURRENT GENERATOR
FIGURE 4.8



PARACHUTE CURRENT GENERATOR
FIGURE 4.9

4.4 GEOTHERMAL ENERGY

Heat from within the earth escapes at a rate of 0.8 Q/yr. Radioactive decay, friction from crustal plate motion and primeval heat may all contribute to the natural heat gradient of 10^{o}C/km of depth in the earth, however, no processes have been developed which can utilize this disperse energy source.

Volcanic activity and tectonism may concentrate geothermal energy to an economically developable level. High temperature resources are associated with tectonic regions as are hot springs with older mountains. Hydrothermal reservoirs, where a heat source of magma is overlain by a permeable formation, produce steam and hot water and are the only type of reservoir to be commercially developed to date. Dry hot rocks hold potential but will require fluid injection and recovery to capture the heat content of the magma. Geopressurized reservoirs trap the heat given off by rapidly subsiding clay in underlying water bearing formations and may provide low temperature water for geothermal power.

Exploration for geothermal deposits is by reconnaissance infra-red aerial photography and ground location of hot water discharges. Drilling, geophysical, and geochemical interpretation provide a follow up evaluation of the resource size and temperature. Risk capital involved in exploration may be prohibitive. The lifetime of an unvented magma system is expected to be in the order of 10^{5} years. This is reduced by one order of magnitude for a vented system. A life of only 50 years is expected at 1000 MW capacity for the largest hydrothermal resources, but only 100 to 500 MW capacity can be installed at most locations. (Ref. 7.) The world wide maximum energy developable from geothermal resources is expected to be about 4×10^{-3} Q/yr (Ref. 1, Volume I).

4.4 GEOTHERMAL ENERGY - (Cont'd)

The geothermal electric power developments throughout the world are summarized in Table 4.5. Hot geothermal water has also been used for home heating and industry process heat, notably in Iceland. Geothermal exploration conducted for B.C. Hydro by Nevin/Sadlier-Brown/Goodbrand Ltd. has located Canada's most promising geothermal resource at Meager Creek near Pemberton. It may produce on the order of 1000 MW if development proves economic (Ref. 48).

TABLE 4.5

WORLD GEOTHERMAL FIELDS*
(Ref. 46)

Country	Field	Installed Capacity (MW)	
Iceland	Namafjall	3	+
Italy	Larderello	360	
	Monte Amiata	26	
Japan	Matsukawa	20	
	Otake	13	
	Akita	10	+
Mexico	Cerro Prieto	75	
	Pathe	4	
New Zealand	Wairakei	160	
	Kawerau	10	
United States**	Geysers	522	+
U.S.S.R.	Pauzhetsk	5	
	Paratunka	1	
		1209	

* Exploration and development, some under the auspices of the UN, is in progress in El Salvador, Chile, Kenya, Tanzania and about 15 other countries.

** In addition, six other massive fields have been identified: studies are in progress to overcome salinity or low temperature in four; two are active steam prospects, the latest discovered by Union Oil in Sandoval Co., N.M., with the discovery well alone reporting 6.5 MW capability.

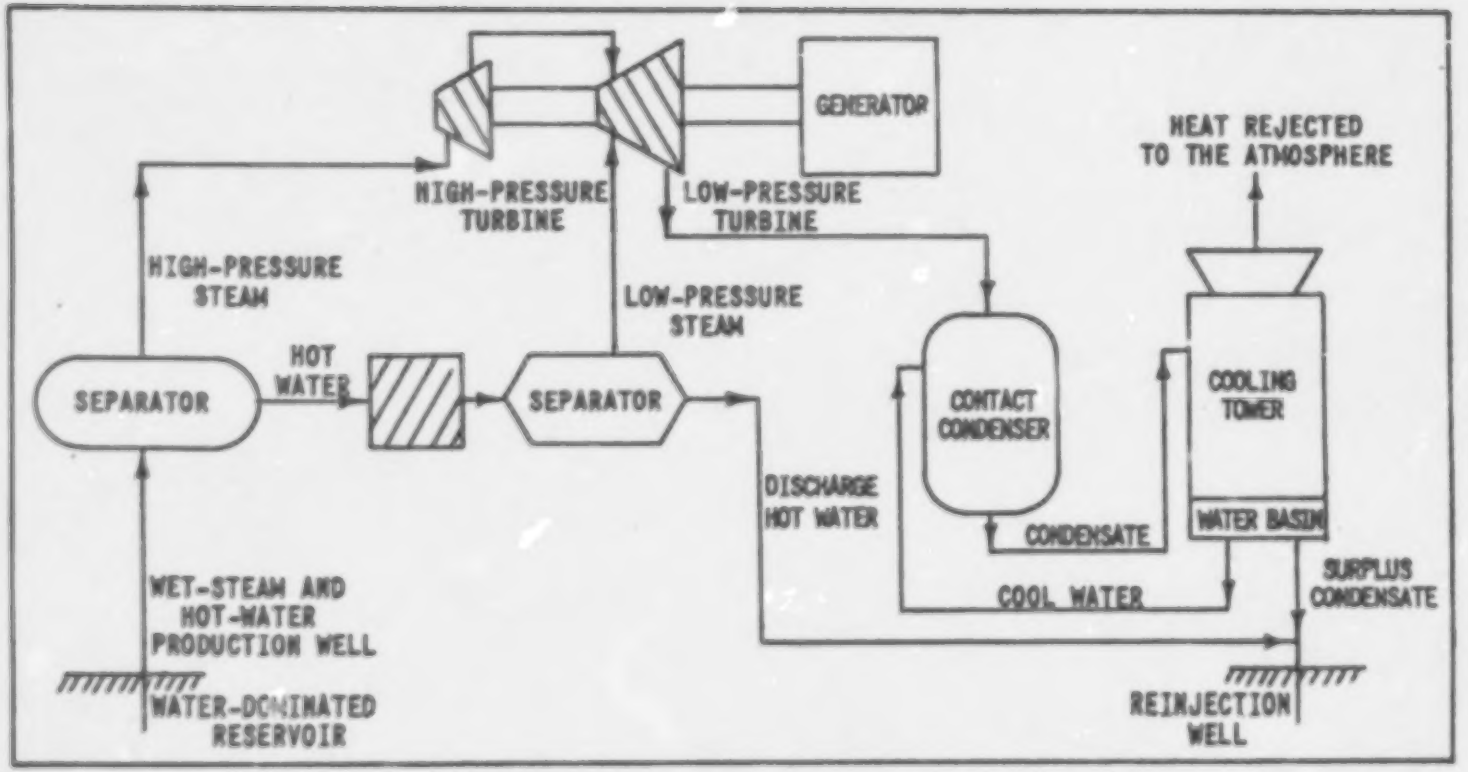
4.4 GEOTHERMAL ENERGY - (Cont'd)

Geothermal power generation is not without environmental and operating problems. The hot brine recovered from drill holes in hydrothermal reservoirs usually has high concentrations of hydrogen sulphide and varying amounts of ammonia, hydrogen, methane and carbon dioxide; which produce both odour and visual pollution. Silicon and calcium carbonate constrict pipes and contaminate ground water, and land subsidence is expected because of the large volumes of water extracted from the reservoir. Corrosion of equipment is also a problem. Fortunately, re-injection of the reservoir water and use of closed cycle cooling apparatus will reduce all these problems except corrosion. Multiple land use may reduce the 0.1 acres/GWh usually associated with geothermal development.

A single steam turbine is conventionally used for power generation from steam dominated hydrothermal reservoirs. Water dominated reservoirs might use a high and a low pressure turbine after flashing the hot water to steam (Fig. 4.10). Although costs and efficiencies will change with the reservoir temperature, they are expected to range from $270 to $540/kW (Ref. 7, Table 8-12, 1972 costs escalated to $1976) installed with up to 15 percent (Ref. 7, Table 8-10) overall efficiency. Plant size is usually small allowing for incremental expansion in units of less than 100 MW. Vapour cycle systems are also envisioned for energy extraction from low temperature reservoirs but costs will presumably be about 20 percent higher than steam cycles and overall efficiencies about 11 percent. (Ref. 7, Table 8-10.)

4.5 SOLID WASTE

Municipal refuse, manure, sewage sludge and some industrial wastes are classified as solid waste products (hog fuel is discussed in Section 3.1(b)) and in some areas hold potential as a supplementary fuel source rather than a disposal problem. Procedures for conversion



WATER DOMINATED GEOTHERMAL GENERATION

FIGURE 4.10

of refuse to energy are depicted in Fig. 4.11 and costs for these and conventional disposal methods are in Table 4.6. Direct burning of solid waste combined with conventional fuel in existing boilers for electric power production appears to hold economic promise in large centres where transportation costs to an existing central power station are not prohibitive. New equipment for use of solid wastes would only be required for separating and shredding procedures. Greater Vancouver is the only area in B.C. to have economic potential for refuse power generation with a possible 30 MW available.

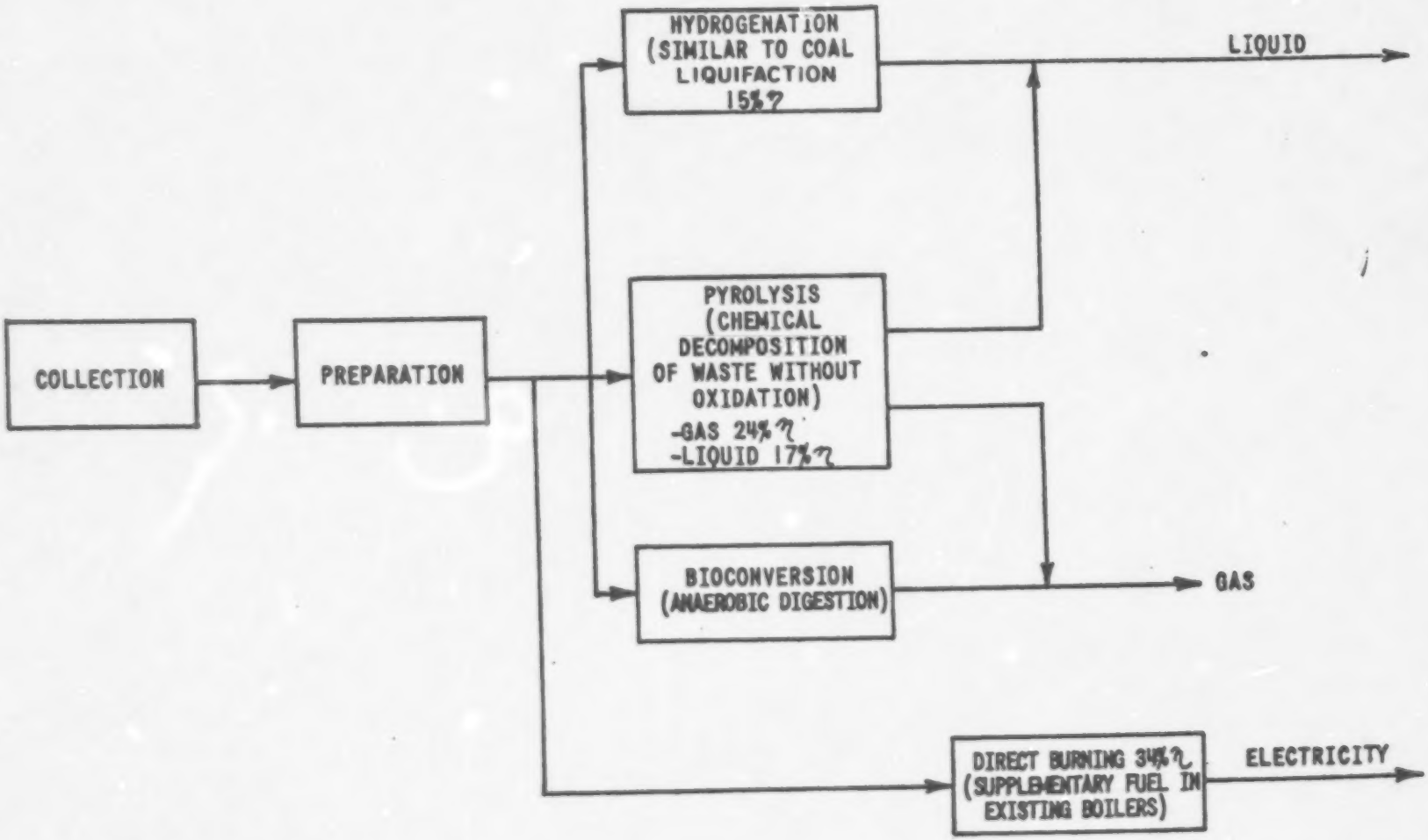
TABLE 4.6

SOLID WASTE DISPOSAL COSTS

Method	Cost ($/ton)	
Pyrolysis	8.40*	Ref. 1 ($1972 escalated to $1976)
Direct Burning	1.20*	Ref. 1 ($1972 escalated to $1976)
Hydrogeneration	Unknown	
Bioconversion	Unknown	
Incineration	11.20	Ref. 1 ($1972 escalated to $1976)
Landfill	3.30	Ref. 3 ($1975 escalated to $1976)

* After accounting for revenue from salable products and preparation costs for the city of St. Louis.

If solid waste is assumed to have a heating value between 5000 and 7500 Btu/lb then the fuel cost from solid waste can be calculated at about 1 mill/kWh for direct burning. However, a maximum of 50 percent of the fuel input for power generation can come from direct burning, the rest must come from fossil fuels, therefore the total fuel cost will be about 11 mills/kWh. Pyrolysis fuel costs will also be about 11 mills/kWh after accounting for reduced overall conversion efficiency and higher processing costs. Biogas production is not expected to become competitive until gas prices reach $4/million Btu (Ref. 24, $3.25/million Btu in $1974). Capital costs have been assumed $500/kW for direct burning and pyrolysis, or the same as coal-fired steam plant costs.



SOLID WASTE GENERATION PROPOSALS
FIGURE 4.11

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SECTION 5.0 - ENERGY STORAGE

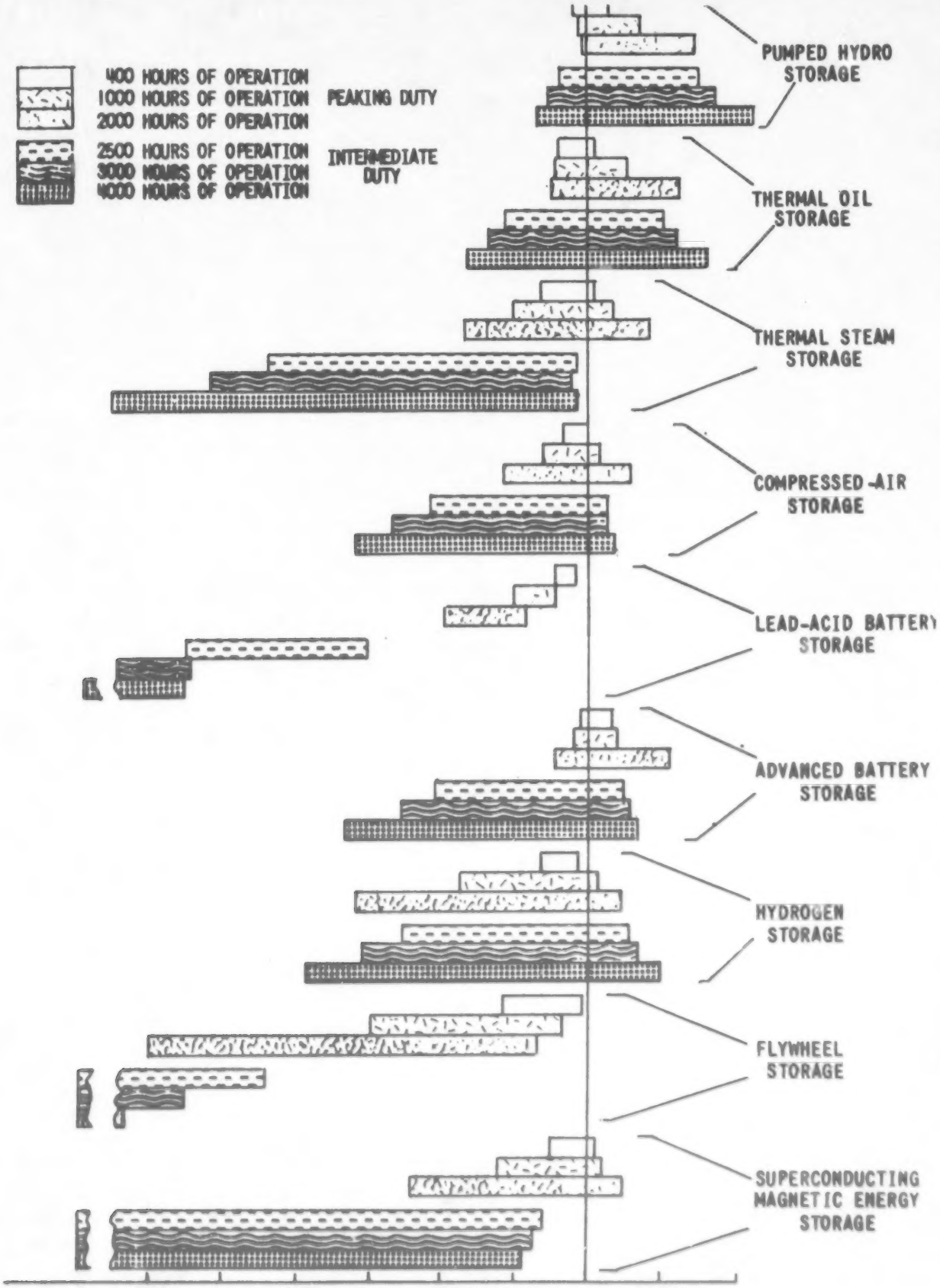
Many of the non-conventional energy sources provide intermittent power which may not coincide with electrical demand. Tidal energy provides power generation twice per day, solar radiation has both daily and seasonal fluctuations and wind and wave energy are somewhat unpredictable. If developed on a small scale, the power from these sources could be absorbed into a large integrated system with inherent storage capable of utilizing the energy whenever available. However, large scale development will require additional energy storage specifically constructed to take advantage of intermittent power. Storage facilities will also enable peak loads to be met with a smaller system capacity.

Pumped water and compressed air storage systems have been constructed to provide large energy storage systems. Batteries, flywheels, thermal storage, hydrogen, and superconducting magnetic storage are being studied as potential alternatives. Fig. 5.1 indicates the relative competitiveness of these systems. Actual costs are discussed only for reasonably well developed storage technologies.

5.1 PUMPED STORAGE

Hydroelectric pumped storage is the only energy storage technology which is currently practical on a large scale for electric utility purposes.

Pumped storage installations consist of two water reservoirs, one of which is at a higher elevation than the other. Water is transferred between the two reservoirs through a tunnel or a penstock during pumping and generating operations. The pumping/generating



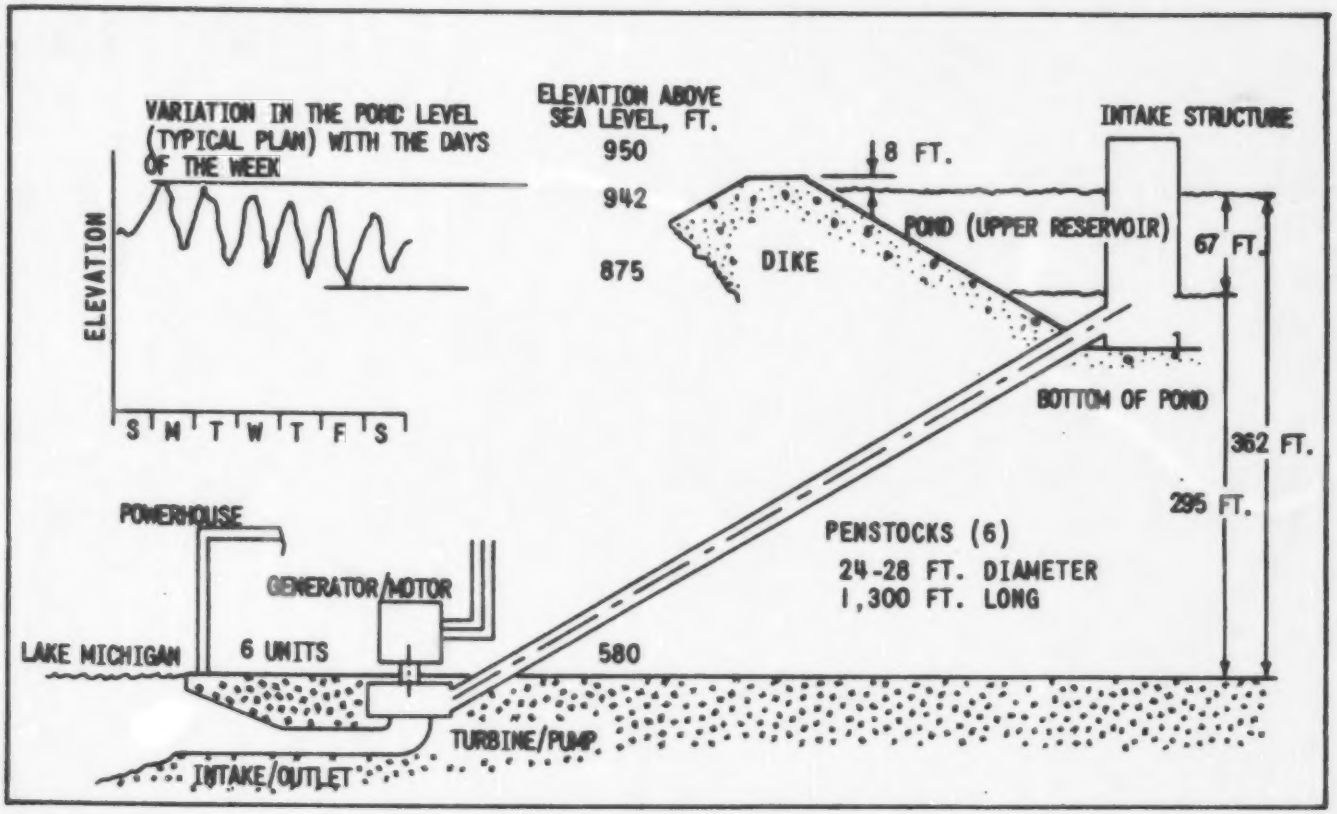
ENERGY STORAGE COMPARISON
FIGURE 5.1

station is located on the lower reservoir and is connected to an electric utility grid by means of transmission lines. A typical pumped storage system is illustrated in Fig. 5.2.

During periods of low demand on the utility grid, (usually during the night) energy is used to pump water from the lower to the upper reservoir. The water stored in the upper reservoir is later released to generate energy during periods of high demand (usually in the late afternoon). Because of energy losses in the pumping operation, about 70 percent of the energy input can be recovered from the storage.

The energy storage capacity of a pumped storage installation is determined by the difference in elevation or head between the two reservoirs and by the volume of water that can be contained in the upper reservoir. Typical pumped storage installations have high heads (500 feet or more) and have sufficient installed capacity to operate on a daily storage cycle. Some larger installations, such as the 2100 MW Bath County development currently under construction in the U.S., have sufficient installed capacity and energy storage to operate on a weekly cycle.

Pumped storage installations have been developed primarily on electrical systems which require additional generating capacity to meet peak electrical loads. Typically, such systems have base load thermal generating stations operating at a high capacity factor to supply the bulk of the system energy demand, with pumped storage and gas turbine capacity to supply peak loads. In contrast, electrical generating in B.C. is predominantly hydroelectric. To supply the peak loads on a hydroelectric system it is usually much more economical to install additional generating units at existing plants than to construct pumped storage installations. Thus, although there are many potential pumped storage sites available in B.C., it is unlikely that these will be developed in the near future.



LUDINGTON PUMPED STORAGE SYSTEM

FIGURE 5.2

5.2 COMPRESSED AIR STORAGE

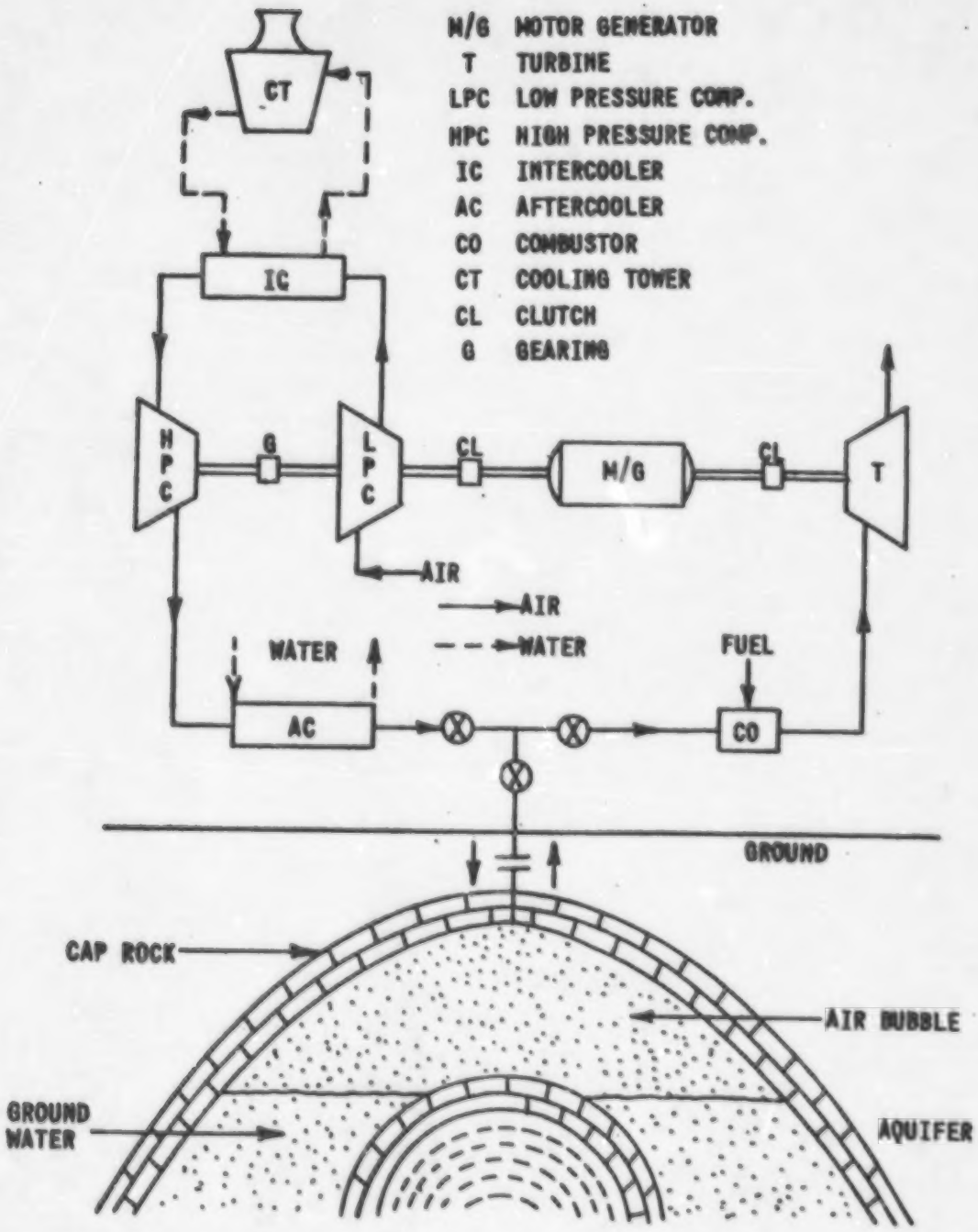
Energy can be stored for peaking power by pumping air into underground storage reservoirs in excavated rock, solution mined salt caverns, mines, abandoned oil and gas reservoirs or aquifers. This system is especially adaptable to gas turbine peaking plants (Fig. 5.3). When running normally, a gas turbine uses 65 percent of its fuel energy to drive the compressor which precedes the turbine. By producing compressed air during off peak hours the capacity of the turbine can temporarily be increased by a factor of three when the stored air is released. Capital cost savings over a conventional gas turbine peaking plant are possible because of the reduced number of turbines, however the overall efficiency of power production is reduced from almost 30 percent to 20 percent.

A 290 MW air storage peaking plant was ordered for Huntford, Germany, in June 1974, and is expected on line in 1977. Two salt caverns with 10^7 $feet^3$ of air storage volume will provide 2 hours of peaking power and require 8 hours recharge time. If a similar plant were constructed in North America the cost would be about $130/kW. (Ref. 12, $117/kW in 1975).

5.3 BATTERIES

Batteries have been used for years to store direct current on a small scale however the lifetime and costs have prohibited large scale energy storage for industrial purposes. Advanced lead-acid, sodium-sulphur or nickel-iron batteries may increase expected lifetimes to years instead of weeks at efficiencies of 50 to 75 percent. Storage system costs of $350/kW have been predicted for advanced lead-acid batteries at a 10-hour constant current discharge rate. (Ref. 5, page 1102.) Battery storage systems would also allow modular expansion with very short lead times.

In British Columbia, a group of researchers at UBC, headed by physicist Rudi Haering, recently reported development of a lightweight test battery with a molydenum disulphide electrode. Dr. Haering



COMPRESSED AIR STORAGE
FIGURE 5.3

5.3 BATTERIES - (Cont'd)

anticipates the battery will store 10 times the energy of a lead-acid battery of equal weight. This battery operates at normal ambient temperature and does not produce any gases. It is similar to a battery being developed by Exxon research in New Jersey, utilizing Titanium Disulphide. Successful development of either or both of these batteries could have a major impact on electric vehicle technology.

5.4 FLYWHEELS

Energy may be mechanically stored in a rotating flywheel, but as yet the technology is undeveloped for large scale utility application. As conceptually designed, flywheel systems will have their massive rotating wheels, weighing hundreds of tons, either vacuum sealed or surrounded by a low pressure helium atmosphere and located underground. Energy is transferred to and from the system by changing the rotation speed with a dual motor/generator.

The major advantages of flywheel storage are the high system efficiency expected, 93 to 95 percent, and the small area required for installation, only 400 feet^2 for a system with 10 MWh of storage. (Ref. 2, Volume II, page 232.) System costs may be as low as $145/kW for a 3 1/2-hour generation period. (Ref. 10, page 22, $110/kW in 1973.)

5.5 THERMAL STORAGE

Thermal storage systems are being specifically developed for use in solar energy thermal-electric and space and water heating systems. Intermittent heat energy must be stored for conversion to electrical peak power or base load generation. Low temperature heat can be stored by raising the temperature of water, concrete or rock, or by melting a material such as Glauber Salts. High temperature storage may be accomplished by melting materials such as sodium hydroxide and sodium fluoride. The heat content properties of these materials are provided in Table 5.1.

5.5 THERMAL STORAGE - (Cont'd)

TABLE 5.1

HEAT PROPERTIES

Water - 62 Btu/ft^3 - ^oF	Glauber Salts - 9400 Btu/ft^3 at 90^oF
Concrete - 29 Btu/ft^3 - ^oF	Sodium hydroxide - 12,000 Btu/ft^3 at 482^oF
Granite - 33 Btu/ft^3 - ^oF	Sodium fluoride - 48,000 Btu/ft^3 at 1818^oF

Thermal storage efficiency will reach 100 percent when used with space and water heating systems if the storage facility is contained within the house. Efficiencies of 80 percent are expected for thermal-electric systems. Because thermal storage is necessary for the operation of solar-thermal systems the storage capital costs have been included in these systems. Comparative storage costs are illustrated in Fig. 5.1.

5.6 HYDROGEN STORAGE

Energy can be stored in chemical form by converting water to hydrogen. Electrolysis, the reverse of fuel cell power production, can be used to convert water and electricity to hydrogen and oxygen. In the future, hydrogen may be produced thermochemically by heating water and adding catalysts; by using direct sunlight in a device similar to a photovoltaic cell to electromotively break down the water into hydrogen and oxygen; or by altering the photosynthetic conditions of some plants so that they generate hydrogen instead of reducing carbon.

Hydrogen may be stored as a gas in pressurized tanks or depleted oil and gas reservoirs or converted to a metal hydride. When required for electrical energy it would be converted in fuel cells or

5.6 HYDROGEN STORAGE - (Cont'd)

thermal cycles. An overall hydrogen system will have generating flexibility advantages and may allow more economic energy transmission than electricity. Capital costs can be estimated from Fig. 5.1.

5.7 SUPER CONDUCTING MAGNETIC STORAGE

Energy can be stored in magnetic fields. A super conducting magnetic storage system with negligible internal resistance can store electrical energy within the magnet windings as potential energy that can be recovered for later use. Conceptual designs plan to bury the super conducting solenoid in bedrock which will absorb the mechanical stresses developed in the coil. Cryogenic cooling and a super conducting switch are required to reduce resistive energy losses within the storage coil.

Overall efficiencies of such a storage device range from 95 percent (Ref. 9, page 5-9) to 84 percent (Ref. 4, page 5-9).

Preliminary engineering studies done at the University of Wisconsin indicate that 9000 MWh of energy could be stored and withdrawn daily with a 10-hour duty cycle for a unit cost of 18 mills/kWh. Capital costs for such a super conducting magnetic storage device could approximate 300 million dollars (1975). For this particular energy storage, the magnetic solenoid would form an arc of a circle 100 m in radius and length.

Energy would be introduced into the magnet by thyristor ac/dc switches similar to these used for dc transmission lines throughout the world.

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APPENDIX A

GLOSSARY OF TECHNICAL TERMS

ACTINIDES - any element in a series of elements of increasing atomic numbers beginning with actinum or thorium and ending with the element of atomic number 103.

AESTHETICS - appreciation of beauty; artistic.

AQUIFER - a water bearing stratum of permeable rock, sand or gravel.

BREEDER REACTOR - a nuclear reactor which converts fertile fuel (usually uranium 238 or thorium 232) to fissile fuel (plutonium 239 or uranium 233) by absorption. In so doing it creates more fissionable material than was originally in the reactor.

CANDU - Candu stands for Canadian heavy water moderated, natural uranium type power reactor.

CRYOGENIC - low temperature physics.

FISSILE - a nucleus which is capable of being split in a nuclear reaction to produce two or more nuclei and significant amounts of energy from a mass loss.

FLUIDIZED BED COMBUSTION - the addition of coal fuel to an inert bed through which combusting air is passed up. (As opposed to

conventional coal fired boilers where a mixture of air and pulverized coal are injected into a furnace and combusted.)

FUSION REACTOR - a nuclear reactor which fuses two or more nuclei together to obtain usable energy in the form of heat. (As opposed to fission reactors which obtain usable energy from the splitting of one heavy nucleus into two or more nuclei.)

GASIFICATION - the addition of hydrogen from steam and oxygen from air to coal to produce combustible gases.

GLAUBER SALTS - a colourless crystalline sulphate of sodium $Na_2SO_4 \cdot 10\ H_2O$.

HELIOSTAT - a device designed to track and reflect the sun's light.

LIQUEFACTION - the addition of hydrogen or removal of carbon from coal to produce combustible liquids.

MHD - Magneto Hydro Dynamics is a process for the direct conversion of the kinetic energy contained in flowing gas particles to electric energy. The hot gas performs the function of an armature in a conventional generator.

MAGMA - molten rock material within the earth from which an igneous rock results by cooling.

PHOTON - a quantum of radiant energy.

PHOTOSYNTHESIS - synthesis of chemical compounds with the aid of radiant energy and especially light.

PHOTOVOLTAIC CELL - semi-conducting electrical junction capable of converting incoming radiant energy (light) to electrical direct current.

Q - a quintillion of 10^{18} Btu, a measure of energy.

TECTONISM - the process of deformation that produces in the earth's crust its continents and ocean basins, plateaus and mountains, folds of strata, and faults.

THYRISTOR - a high voltage dc rectifying valve.

TIDAL BARRAGE - dam constructed to force water flowing into or out of a tidal basin through a turbine.

APPENDIX B

COST CONVERSION TABLE
(Assumed Inflation Factors)

Year	Assume Inflation %	Factor
1970	5	1.54
1971	5	1.47
1972	7	1.40
1973	8	1.31
1974	10	1.21
1975	10	1.10
1977	8	.93
1978	7	.87
1979	5	.82
1980	5	.78
1981	5	.75
1982	5	.71
1983	5	.68
1984	5	.65
1985	5	.61

All cost quoted in report are 1976 unless otherwise stated. Conversion to 1976 was accomplished with the above table.

TABLE 1.1 ENERGY SUMMARY

ENERGY SOURCE	ENERGY CONTENT (RESERVES & RESOURCES) WORLD	ENERGY CONTENT (RESERVES & RESOURCES) B.C.	GENERATION METHOD	STATUS	TECHNICAL PROBLEMS	LAND USE ACRES/GWH	ENVIRONMENTAL & POLLUTION PROBLEMS	INVARIANT	EFFICIENCY %	CAPITAL COST $/kW	ANNUAL COSTS %	CAPACITY FACTOR %	INTEREST DURING CONSTRUCTION %	FUEL MILLS/ kwH	ENERGY COST MILLS/ kwH
HYDRO	4.3×10^{-2} Q/YR	8.37×10^{-4} Q/YR	HYDRO TURBINE	EXISTING		1 - 30	FISHERIES AND WILDLIFE, LAND USE RELOCATION OF POPULATION	YES	80 - 90	500 - 850	12	40 - 80	25	0	15 - 25
COAL	1.9×10^{2} Q	4.4×10^{-2} Q (THERMAL QUALITY)	STEAM CYCLE	EXISTING	NONE	.5 WITH MINING	THERMAL, NOx, SO_2 AND SOLID WASTE	NO	32	500	14	75	25	5 - 10	18 - 23
			FLUID BED	1985			THERMAL (NO SULPHUR, LOW NO_2)	NO	36	420	14	75	25	4 - 9	15 - 20
			GASIFICATION & GAS TURBINE	1985	GASIFICATION TECHNOLOGY			NO	21 - 26	350	14	75	25	7 - 14	18 - 23
			REFORMER FUEL CELL	1990	GASIF. TECHNOLOGY PRECIOUS METAL ANODES, CELL LIFE		LIQUID WASTE	NO	36 - 44	450	14	75	25	4 - 8	18 - 20
			GASIFICATION OR LIQUIFICATION AND COMB. CYCLE	1990	GASIF. TECHNOLOGY AND LIFETIME			NO	29 - 30	500	14	75	25	5 - 10	18 - 23
			MHD TOPPING	1995	CHANNEL EROSION AND ELECTRODE LIFE		HIGH NOx & SO_2	NO	50 - 60	680	15	75	25	3 - 6	22 - 25
NATURAL GAS	1.0×10^{1} Q	4.0×10^{-2} Q	STEAM CYCLE	EXISTING				NO	38 - 40	350	13	75	25	15	24
			GAS TURBINE	EXISTING			SOME NOx	NO	27 - 33	225	14	75	25	20	28
			FUEL CELL	1990	PRECIOUS METAL ANODES, CELL LIFE	.03	LIQUID WASTE	NO	45 - 55	230	15	75	25	12	19
			COMB. CYCLE	EXISTING				NO	36 - 38	325	14	75	25	16	25
			MHD TOPPING	1995	CHANNEL EROSION & ELECTRODE LIFE		HIGH NOx & SO_2	NO	50 - 60	425	15	75	25	11	22
			STEAM	EXISTING				NO	38 - 40	375	14	75	25	15	26
OIL	1.1×10^{1} Q	1.4×10^{-2} Q	GAS TURBINE	EXISTING		.04 (OIL)		NO	27 - 33	235	14	75	25	20	28
TAR SANDS	3.1Q	0.0Q	COMB. CYCLE	EXISTING		.5 (TS)		NO	36 - 38	340	14	75	25	16	25
OIL SHALES	1.1Q	0.0Q	MHD TOPPING	1995	CHANNEL EROSION & ELECTRODE LIFE	.5 (OS)	HIGH NOx & SO_2	NO	50 - 60	450	15	75	25	11	24
FISSION (NON-BREEDER)	4.1Q	7.0×10^{-1} Q [2]	CANDU HWR - STEAM	EXISTING		.4 WITH MINING	THERMAL, RADIOACTIVE WASTE	NO	32	900	14	75	30	2	27
			LWR - STEAM	EXISTING			THERMAL, RADIOACTIVE WASTE	NO	32	770	14	75	30	3	24
			HTGCR - STEAM	EXISTING	FUEL CYCLE		SOME THERMAL, RADIOACTIVE WASTE	NO	39	510	14	75	30	2	16
			HTGCR - COMB. CYCLE	1990	FUEL CYCLE		RADIOACTIVE WASTE	NO	45	510	14	75	30	2	16
FISSION (BREEDER)	1.6×10^{2} Q	2.8×10^{1} Q [2]	LMFBR	1987 COMMERCIAL CONSTR. START	FUEL CYCLE		SOME RADIOACTIVE WASTE	NO	42	590	14	75	30	2	18
			GCFBR - STEAM	AFTER HTGCR & LMFBR	FUEL CYCLE	.05	" " "	NO	39	510	14	75	30	2	16
			GCFBR - COMB. CYCLE	AFTER HTGCR & LMFBR	FUEL CYCLE		" " "	NO	45	510	14	75	30	2	16
FUSION	6.0×10^{6} Q	VERY LARGE	DEUTERIUM-TRITIUM	2000-2050	CONTAINMENT	.05	LOW RADIOACTIVE WASTE	NO	50	590	14	75	30	0	16
	8.0×10^{9} Q	VERY LARGE	DEUTERIUM-DEUTERIUM	?	DEVELOPMENT & CONTAINMENT	.05	LOW RADIOACTIVE WASTE	NO	50	590	14	75	30	0	16
SUNLIGHT	2.4×10^{3} Q/YR [1]	2.5 Q/YR [3]	THERMAL-STEAM	1995	LOW COST CONCENTRATORS	2 - 3	THERMAL	YES	20	3,000--7,500	14	90	30	0	155 - 390
			PHOTOVOLTAIC	1995	MASS PRODUCTION	4 - 6		YES	10 - 15	950--25,000 [1]	14	42	30	0	47 - 1,250 [1]
			PHOTOVOLTAIC SATELLITE	1995	LAUNCHING COSTS	0.3		NO	8	350--400,000 [1]	15	90	30	0	9 - 9,890 [1]
PHOTOSYNTHESIS	1.2 Q/YR	1.0×10^{-3} Q/YR	PHOTOSYNTHESIS-STEAM	EXISTING	FUEL TRANSPORTATION	50 - 750		YES	1/2	500	14	72	25	10	24
WIND	1.0 Q/YR	1.0×10^{-3} Q/YR	WDG	1980-1985	BLADE FAILURE	20	AESTHETICS, NOISE, DRAFTS BLADE FAILURE SAFETY	YES	35 - 40	500 - 850	14	15 - 40	25	0	25 - 113
OCEAN THERMAL GRADIENTS	1.0×10^{-1} Q/YR	0.0Q	VAPOUR CYCLE	CONCEPTUAL	NO B.C. RESOURCE, PUMPING SYSTEM	0.2	THERMAL REDISTRIBUTION	YES	3	11,000-33,000	15	80	30	0	306 - 918
WAVE	7.5×10^{-1} Q/YR	2.3×10^{-4} Q/YR	WAVE MACHINE	LABRATORY BENCH TESTING (1990)	TRANSMISSION	6MW/MILE		YES	40 - 66	1,000-	14	60	30	0	35 - 70
TIDAL (BARRAGE)	1.9×10^{-3} Q/YR	> 10^{-4} Q/YR	BARRAGE HYDRO TURBINE	EXISTING	B.C. TIDAL RANGE SMALL	1 - 5 [4]	FISHERIES, CURRENT PATTERN CHANGES, SILTATION	YES	10 - 25	800-1,800	14	25	30	0	66 - 150
OCEAN CURRENTS	8.0×10^{-5} Q/YR	1.0×10^{-7} Q/YR	CURRENT GENERATOR	CONCEPTUAL	TRANSMISSION	UNDERWATER		YES	20	1,450	14	60	30	0	50
GEOTHERMAL	4.0×10^{-3} Q/YR	1.0×10^{-4} Q/YR	STEAM CYCLE	EXISTING	CORROSION & RISK CAPITAL	.1	H_2S AMMONIA, THERMAL NITROGEN, LAND SUBSIDENCE	YES	15	270 - 540	14	70	30	0	8 - 16
			VAPOUR CYCLE	CONCEPTUAL	CORROSION, HEAT EXCHANGER & RISK CAPITAL	.1	THERMAL, LAND SUBSIDENCE	YES	11	325 - 650	14	70	30	0	10 - 19
SOLID WASTE	1.0×10^{-3} Q/YR	1.0×10^{-4} Q/YR	PYROLYSIS	ADVANCED	SHREDDING & SORTING	.05	THERMAL, NOx, SO_2	NO	20	500	15	70	30	11	27
			DIRECT BURNING-STEAM	EXISTING	SHREDDING & SORTING	.05	THERMAL, NOx, SO_2	NO	34	500	15	70	30	11	27

NOTES: INFORMATION NOT DISCUSSED IN REPORT HAS BEEN ASSUMED BY THE GENERATION PLANNING DEPARTMENT, B.C. HYDRO.
COSTS ARE IN 1976 DOLLARS.
COSTS AND LAND USE DATA ARE FOR B.C. LOCATIONS.

FOOTNOTES:
1) PHOTOVOLTAIC COSTS ASSUMING 1976 TECHNOLOGY.
2) B.C. FISSION RESOURCES ARE ACTUALLY CANADIAN RESOURCES.
3) SUNLIGHT RESOURCE ASSUMES 100% OF EARTH'S SURFACE USED TO COLLECT SUNLIGHT.
4) TIDAL ENERGY LAND USE COULD BE ZERO AS ESTUARY SIZE DOES NOT CHANGE.